AD-A113 236 ECLECTECH ASSOCIATES INC NORTH STONINGTON CT F/G 17/7
DRAFT SRA/RA SYSTEMS DESIGN MANUAL FOR RESTRICTED WATERWAYS.(U)
FEB 82 W R BERTSCHE, M W SMITH, K L MARINO DOT-CG-835285-A
UNCLASSIFIED EA-80-U-035 USCG-D-77-81 NL

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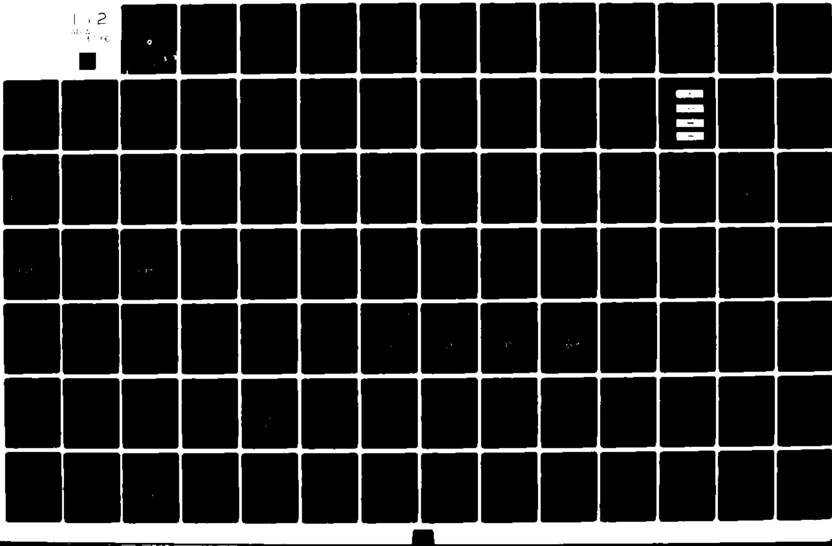

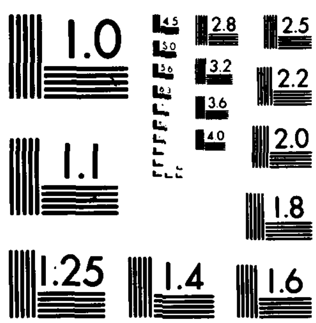

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REPORT NO. CG-D-77-81

DRAFT
SRA/RA SYSTEMS DESIGN MANUAL
RESTRICTED WATERWAYS

Eclectech Associates, Inc.
North Stonington Professional Center
North Stonington, Connecticut 06359

Interim Report

February 1982

Prepared for

Department of Transportation
United States Coast Guard
Office of Research and Development
Washington, D.C. 20593

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CG-D-77-81	AD-A113 236	

4. Title and Subtitle	5. Report Date
Draft SRA/RA Systems Design Manual for Restricted Waterways	February 1982
	6. Performing Organization Code
7. Author(s) W.R. Bertsche, M.W. Smith, K.L. Marino, R.B. Cooper	8. Performing Organization Report No. EA-80-U-035
9. Performing Organization Name and Address Eclectech Associates, Inc. North Stonington Professional Center North Stonington, Connecticut 06359	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DOT-CG-835285-A
12. Sponsoring Agency Name and Address Department of Transportation U.S. Coast Guard Office of Research and Development Washington, D.C. 20593	13. Type of Report and Period Covered INTERIM REPORT 14. Sponsoring Agency Code G/DST-1

15. Supplementary Notes

16. Abstract

The Aids-to-Navigation Systems Study Phase II, conducted for the U.S. Coast Guard by Eclectech Associates, Incorporated, resulted in this "Draft SRA/RA Systems Design Manual for Restricted Waterways." This manual has been written to support aid to navigation system design and maintenance functions performed at the District Office. In Section 1, the procedure presented applies the findings of the project to the specific problem of assigning priorities for the maintenance of individual aids when resources are limited. In Section 2, the procedure presented relates channel or harbor conditions to the aid to navigation systems needed to provide adequate performance. In Section 3, instructions and piloting performance data are provided for design methods which seek to "manage" the risk of accidents. A second approach described is to design AN systems while considering the cost tradeoff between providing an aid to navigation system versus the value of the increased safety.

A series of data collection efforts were conducted on shiphandling simulators and at sea specifically to derive design data for use in this manual. There were five visual simulator efforts, three radio aid simulator efforts, and two at-sea data collections. The draft manual is highly annotated with reference to these efforts.

17. Key Words	18. Distribution Statement
aids to navigation, short-range aids to navigation, visual aids to navigation, visual piloting, radio aids to navigation, (see 17 cont'd)	Document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif (of this report)	20. Security Classif (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	177	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

17. KEY WORDS (Cont'd)

electronic aids to navigation, radio aids piloting, piloting, restricted waterways, ship simulation, shiphandling simulation, bridge simulation, radio aids simulation, discrepancy response, risk management, cost/benefit analysis

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the United States Coast Guard personnel who supported and contributed to the project. They include Captain Donald A. Feldman who participated in the original decisions that structured the project; Captain J.T. Montonye, Commander John F. Roeber, and Lieutenant John Anthony who provided continuing guidance throughout the project; Mr. Jack M. Ligon who helped structure the radio aids to navigation experiments; and Lieutenant Commander Kent Kirkpatrick who reviewed the manual. We particularly want to thank Mr. Karl Schroeder for his constant help and support in all phases of the project.

We would like to express our appreciation to those at the Maritime Administration's Computer Aided Operations Research Facility (CAORF) in New York for their participation in the experiment that was performed there. We particularly want to thank Mr. Joseph J. Puglisi, Managing Director, for his guidance; and Mr. Henry Grossman and his staff for their advice and help in the preparation and conduct of the simulation.

We would also like to thank all of the pilots who participated as consultants or as subjects in the experiments. Each of them provided the insights of the practitioner to our efforts. The pilots in the CAORF experiment were from the Sandy Hook Pilots Association and the Delaware Bay Pilots Association. Those who particiated in the simulations at North Stonington, Connecticut, were from Northeast Marine Pilots, Inc. The Association of Maryland Pilots provided access to the ships for the purpose of tracking and accommodated our many unique requirements for collecting the at-sea data.

Overall, a great many capable and enthusiastic people made this project possible and each have our sincere, heartfelt appreciation.

PREFACE

This manual is a product of the United States Coast Guard's Performance of Aids to Navigation Systems Project, Phase II. The objective of the project was the development of an analytical or decisionmaking tool for evaluating aid systems in individual harbors and channels as to their ability to support effective pilotage and, thus, safe and expeditious shipping.

The problem was treated as a system with the several aspects studied as separate but interlocking components. Early components were the cataloguing of existing conditions in major U.S. harbors to ensure later applicability and analysis of variables that were likely to have major effects on piloting. The decision was made to invest the greater part of the effort in "real-time, man-in-the-loop" simulation especially designed to relate aid systems of interest, possible channel conditions, and piloting performance. A first exploratory analysis of visual piloting was done at the Maritime Administration's Computer Aided Operations Research Facility (CAORF) in New York. Later data collection was done on a simulator developed for the project at Eclectech Associates, Inc., in North Stonington, Connecticut. A comparison of results on the two simulators found performance functionally the same for the intended purpose. The additional efforts included four visual and three radio aids experiments on the second simulator. An at-sea data collection was also done in preparation for validation of the USCG/EA simulation and the experimental results. All components are described in separate reports that are listed in the bibliography.

The manual draws on the findings of all the components to provide guidance for three applications:

- The assigning of priorities for maintenance to individual aids when resources are limited

- The evaluation of existing or projected aid systems as to their ability to provide adequate piloting

- The support of management decisions about the cost of aid systems and the risk and cost of accidents

It should be understood that the manual as it is presented here is not a finished product, but an exploration of possibilities using the findings presently available. Still necessary are the evaluation and inclusion of radar piloting, a validation of the USCG/EA simulator for restricted waterway piloting, and a trial implementation of the procedures in an existing waterway.

It should also be pointed out that, for the U.S. Coast Guard's purposes, the manual does not stand alone. Coast Guard decisions on aid systems must be based on a number of factors; including the relative cost and effort of installation, the relative reliability of a system and the cost and effort of maintenance, the detection distance and other

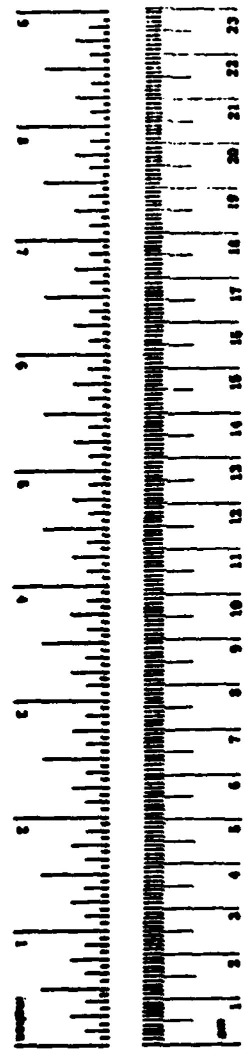
environmental conditions to be expected, the importance of piloting precision for conditions, the subjective preference of the users, and the piloting performance to be expected with a system. The first and second applications of this manual are concerned almost entirely with piloting performance. The third application explores techniques which include a wider set of factors in the decision.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

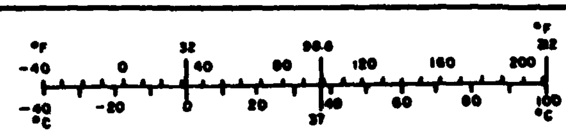
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

INTRODUCTION

The Aids-to-Navigation Systems Study Phase II, conducted for the U.S. Coast Guard by Eclectech Associates, Incorporated, resulted in this "Draft SRA/RA Systems Design Manual." The study and the manual were planned to aid the Coast Guard in designing and evaluating systems of aids to navigation to meet the user's needs and minimize associated risks to safety and expeditious passage. The manual is unique in that it is based on empirical data collected specifically for the purpose of developing such an analytical technique. It applies the findings of the study to three practical and systematic procedures: assigning maintenance priorities to individual aids, evaluating the adequacy of SRA systems, and applying risk management and cost/benefit techniques to the design of AN systems. It will facilitate the evaluation of the contribution of such specific elements of the aids to navigation program as aid placement, quantity and development of maintenance resources, use of RACONS, design of navigation radio displays, etc. Finally, the capability will provide a quantification of accident risks and costs associated with the installation and/or removal of fixed, floating, and electronic radio aids to navigation.

This manual also provides fundamental support to policies of the U.S. Coast Guard dealing with the operational limitations of specific ports and Coast Guard responses to the changes in users or ports. Cost savings will be realized both when structuring these policies and when defending them during subsequent reviews.

The Draft SRA/RA Systems Design Manual is derived from data collected on shiphandling simulators and at sea. Although the manual is preliminary, sample application of its techniques suggest that early application by the U.S. Coast Guard to already existing problems is imperative. A few qualifications remain, however, which prevent this immediate implementation.

First, all data in the manual were derived at the exclusion of radar pilotage. Since the quality of radar information has been shown to significantly influence piloting performance,[1,2] the effects of aids to navigation design on radar pilotage must be included in the manual. Recent and proposed requirements for automatic radar plotting capabilities (i.e., ARPA), the introduction in U.S. waterways of navigation enhancements such as RACONs, and the use of innovative piloting techniques such as course cursor piloting, further signify the need to include radar pilotage in the manual.

Secondly, while all AN data collection was conducted either on CAORF (i.e., the Computer Aided Operations Research Facility located at Kings Point, New York) or the U.S. Coast Guard simulator at Eclectech Associates; neither of these simulators has been validated for restricted waterway conditions. Subsequent research,[3,4] however, has shown the two simulators are similar, specifically in their usefulness

for investigating relationships between aids to navigation and piloting performance. Nevertheless, there remains a requirement to compare the Coast Guard simulator with real-world conditions and thereby validate the data and conclusions contained in this manual.

A final requirement for the SRA/RA Systems Manual which must be performed before the Coast Guard can put it to effective use, is a demonstration of the manual through its controlled implementation in an existing U.S. harbor. The effort required would use the manual to identify aids to navigation inadequacies in a particular harbor, and propose adequate design solutions. The study would first measure at-sea piloting performance with the identified deficiencies. Proposed solutions would then be implemented in the waterway, and piloting performance remeasured. A comparison of piloting performance between preimplementation and postimplementation of the manual's recommendations would serve as an indicator of the manual's overall effectiveness.

These additional requirements are presently under consideration by the U.S. Coast Guard and if initiated will culminate in a revision of the Draft AN SRA/RA Systems Design Manual to provide the U.S. Coast Guard with an easy to use, yet thorough and credible tool for the cost efficient design, evaluation, and maintenance of its aids to navigation systems.

APPLICATION OF THE SRA/RA SYSTEM DESIGN MANUAL

This manual has been written to support aid to navigation system design and maintenance functions performed at the District Office. Three specific functions are supported. Descriptions of the functions and detailed instructions are contained in the three principal sections of this manual. Appendices provide the data and forms required in the design and analysis processes.

Section 1. The Assignment of Maintenance Priorities to Individual Aids

The procedure presented applies the findings of the project to the specific problem of assigning priorities for the maintenance of individual aids when resources are limited. Directions are given for assigning a number to individual aids. This number indicates how critically piloting performance is dependent on each particular aid, compared to others in the same channel or nearby channels. The higher the number, the more critical the aid is to safe navigation. The U.S. Coast Guard might give additional priority to major shipping channels, to channels used by high-risk ships, to channels in proximity to bridges, etc. At the headquarters level, these numbers may be used to justify the allocation of maintenance resources and to establish a balanced deployment of maintenance vessels as a function of minimum response time to high priority aids.

Section 2. The Evaluation of the Adequacy of Short-Range Aid Systems

The purpose of this section is to relate channel or harbor conditions to the aid to navigation systems needed to provide adequate

performance. The specification of adequate SRA configurations allows a top level evaluation of whether an existing configuration is either adequate, inadequate, or redundant. By "adequate" is meant that the piloting performance should be as precise as any observed in the project and/or will be the best that can be expected under the specific channel conditions. By "inadequate" is meant that the piloting perfomance might be less precise and significantly poorer than that observed under similar conditions with more aids. By "redundant" is meant that, while piloting performance may be adequate and precise, similarly adequate and precise performance might be achieved with fewer aids. The methodologies discussed in this section support a design program which seeks to obtain uniform piloting performance throughout the major channel systems of the United States.

Section 3. The Application of Risk Management and Cost/Benefit in the Design of Aid to Navigation Systems

Instructions and piloting performance data are provided for design methods which seek to "manage" the risk of accidents. Two risk management design methods are suggested. The first method seeks to design for minimum risk, in which case the designer seeks to minimize the risk of accidents. The second method seeks to design for an acceptable risk of accidents in which case the accident risk calculated for an actual channel with an acceptable safety record can be used as a goal for the channel under considerations.

A second approach to the design of AN systems is to consider the cost tradeoff between providing an aid to navigation system versus the value of the increased safety. Instructions are provided which achieve an estimation of the savings in accident costs versus the cost of the AN configuration under consideration. Cost/benefit analyses techniques may be applied to the problem of reducing groundings in narrow waterways where there is usually no loss of life nor injury resulting from the accident. The cost/benefit approach may not be appropriate when loss of life is an issue as in the case of collisions in congested waterways. Yet, even the cost of preventing loss of life may have to be equated for the purposes of making policy decisions within the context of limited funds. The cost/benefit design approach may be required to achieve equitable distribution of funds and to justify appropriations for improvements.

SCOPE OF THE DRAFT SRA/AN SYSTEMS DESIGN MANUAL

The design procedures described in this manual apply to restricted waterways found in U.S. coastal ports. A study of these ports[5] has shown that there are in excess of 1320 nm of these channels. Presently, there are approximately 4500 floating or fixed aids at the channel edges and 450 ranges marking these waterways.

These waterways exhibit the following characteristics:

- Channels 30 to 55 feet in depth
- Channels 350 to 1000 feet in width

- Channels which support operation of vessels equal to or greater than 30,000 dwt

This manual addresses the following AN systems as they are applied in these waterways:

SRA
- Floating/fixed aids at the channel edge
- Range lights
- Radar reflectors (data not yet available)

Radio Aids
- Display characteristics
- Signal noise characteristics
- Tracker characteristics

Findings of this manual cannot be extrapolated to inland waterway operations or operations of tugs and tows or pushboats.

DATA SUPPORTING THE SRA/RA SYSTEM DESIGN MANUAL

A series of data collection efforts were conducted on shiphandling simulators and at sea specifically to derive design data for use in this manual. There were five visual simulator efforts to collect piloting performance data on the relationship among physical channel dimensions, environmental conditions, ship characteristics, and SRA arrangements. The SRA arrangements evaluated included turn and straight channel buoy configurations and range light designs. There were three Radio Aids simulator efforts to collect piloting performance data for digital, graphic, perspective, and steering display formats. One of these efforts evaluated the effects of signal noise and filter characteristics. To complement the simulator efforts, there were two at-sea collections of performance data for visual, radar, and Radio Aids piloting. Individual reports describing each of these efforts are listed in the bibliography.

This draft version of the SRA/RA Systems Design Manual is widely annotated with explanatory notes. These notes serve to indicate the data which support statements which might otherwise appear subjective. Throughout the text all references to explanatory notes are indicated by a raised figure at the end of the statement. It is anticipated that these explanatory notes would not be included in a final version of the manual.

EXPLANATORY NOTES FOR EXECUTIVE SUMMARY

1. R.B. Cooper, W.R. Bertsche, and G.J. McCue. "Simulator Evaluation of Predictor Steering Short Range Collision Avoidance and Navigation Displays, The Advanced Bridge Design Program." U.S. Maritime Administration, Washington, D.C., November 1979.

2. J.N. Hayes and E.D. Wald. "Effectiveness of Three Electronic Systems as Collision Avoidance Aids; A Simulator Investigation in a Congested Harbor Approach." U.S. Maritime Administration, Washington, D.C., July 1980.

3. M.W. Smith and W.R. Bertsche. "Aids to Navigation Principal Findings Report on the Channel Width Experiment: The Effects of Channel Width and Related Variables on Piloting Performance." U.S. Coast Guard, Washington, D.C., January 1981.

4. W.R Bertsche, D.A. Atkins, and M.W. Smith. "Aids to Navigation Principal Findings Report on the Ship Variables Experiment: The Effect of Ship Characteristics and Related Variables on Piloting Performance." U.S. Coast Guard, Washington, D.C., April 1981.

5. W.R. Bertsche and R.T. Mercer. "Aids to Navigation Configurations and the Physical Characteristics of Waterways in 32 Major U.S. Ports." U.S. Coast Guard, Washington, D.C., October 1979.

Section 1

THE ASSIGNMENT OF MAINTENANCE PRIORITIES TO INDIVIDUAL AIDS

1.1 INTRODUCTION AND APPLICATION

The procedure presented here applies the findings of the project to the specific problem of assigning maintenance priorities to individual aids when resources are limited. The priorities assigned here are based entirely on the value of the aids for the piloting task as analyzed in the project. For the U.S. Coast Guard's needs, this is only one consideration. Other mechanisms exist for evaluating the severity of the discrepancy and the urgency that the discrepancy demands. In actual practice the Coast Guard would have to provide a more complex mechanism for considering a number of factors.

Some description of the scope of application is necessary. Directions are given for assigning a number to individual buoys in competition with other buoys in the same channels, or nearby channels. The rules apply to any aid, fixed or floating, that is at the edge of the channel and used by the pilot as a buoy is used. The word "buoy" appears in the following discussion because it is the most vulnerable aid among the possibilities. A possible extension of the process of assigning priorities is the adjustment of the numbers in competition with other channels over a wider area. Priorities might be adjusted for the relative width of competing channels; or priority might be given to major shipping channels, to channels used by high-risk ships, to channels in proximity to bridges, etc. It is not a legitimate extension of the procedure in this section to assume that buoys given low priority may be eliminated. The more elaborate procedure of Section 2 and 3 are meant to assist in such a decision. It is not appropriate to interpret these numbers as predicting the risk of grounding: Section 3 is an analysis of the relative risk of channel systems. The numbers assigned here have their use in quantifying the importance of a buoy relative to those around it.

The numbers indicate the relative rank or order of priority. They range from a high of 5 for a buoy which should be serviced immediately to a low of 1 for a buoy that can wait while others are serviced. The number assigned a buoy is partially determined by its location in one of three regions of the channel: the turn region, the recovery region, or the trackkeeping region. Those in the turn region have the highest priority; those in the recovery region, the next priority; and those in the trackkeeping region, the lowest. A channel that has no trackkeeping region; because of its short length or because of conditions; will have a truncated range of values with all the buoys being assigned high numbers and none low. In addition to determination by the regions, the numbers within regions are adjusted for channel conditions such as ship size, traffic, and environmental conditions. As examples, turn region buoys can be 5 (the turnpoint of a noncutoff turn), 4, or 3 under the least demanding conditions; buoys in the recovery region can be 3 or 4, depending on conditions; only buoys in the trackkeeping regions can be 2 or 1.

1.2 THE PROCEDURE

The necessary first steps of this - and the other procedures in this manual - are the specifications of the channel conditions and the division of the channel into regions. These steps are described in Appendix A: The Determination of Navigational Regions. The discussion from here will assume this has been done.

The procedure for assigning a number to an individual buoy is summarized in Table 1-1. The underlying logic is discussed here to allow flexibility for application to a variety of situations. An illustrative example follows the description of the procedure.

1.2.1 Buoys in the Turn Region

Common turn configurations are illustrated in Figure 1-1. For a noncutoff turn the turnpoint buoy, or inside apex buoy, is assigned the highest possible number, 5, because it is essential to the severest maneuver the pilot and ship can make. For such a turn, pilots concentrate on this buoy both to judge the position at which to begin the turn and to judge their track through the turn.[1]

When any other single buoy is the only one marking a turn, it is also assigned a 5, regardless of the configuration of the turn or the location of the buoy. Obviously, in such a turn, there are no alternatives.[2]

Other buoys outlining the turn are assigned numbers 3 or 4,[3] depending on conditions. Some possibilities are illustrated in Figure 1-1. More buoys than those illustrated are probably redundant and should not be assigned such a high number.[4] Whether a buoy should be 3 or 4 depends on the following conditions:

- For turns of <u>angles larger than 15 degrees</u>, the outlining buoys should be 4. The severity of the higher angle turn makes it more critical that the pilot be able to judge his position and velocity.[5]

- For turns negotiated by <u>ships larger than 30,000 dwt</u>, the outlining buoys should be 4. The less maneuverable ship makes the pilot's judgements more critical.[6]

- If there is a possibility that <u>traffic</u> will be encountered in the turn, the buoys should be assigned a 4. It is important that they outline the space available for the selection of alternate tracks.[7]

- Some <u>wind</u> conditions are a special problem. Winds that combine a strong crosstrack component (approximately 17 knots perpendicular to the track) with some unpredictability of direction require the priority of the buoys be increased to 4. Such perturbation makes it more critical that the pilot be able to make new judgements of his position and velocity.[8]

- If there is <u>current</u> across the ships' tracks of a magnitude that requires a compensating drift angle of more than 2 to 5 degrees, the

TABLE 1-1. ASSIGNING A MAINTENANCE PRIORITY TO AN INDIVIDUAL BUOY

TURNS	
• Turnpoint buoy for noncutoff turns	5
• Single buoy marking a turn	5
• Other buoys outlining a turn	start at 3
– Turn angle greater than 15 degrees	4
– Ships larger than 30,000 dwt	4
– Traffic in turn	4
– Wind across track	4
– Current across track	4
RECOVERY	
•	start at 3
• Ships larger than 30,000 dwt	4
• If no pullout buoy, next is	4
• Low number or density of buoys	
– Long-spaced staggered arrangements	4
– One-side arrangements, any spacing	4
TRACKKEEPING	
•	start at 1
• Strong wind across track	+1
• Low number or density of buoys	
– Long-spaced staggered arrangements	+1
– One-side arrangements, any spacing	+1
• Ship larger than 30,000 dwt	+1

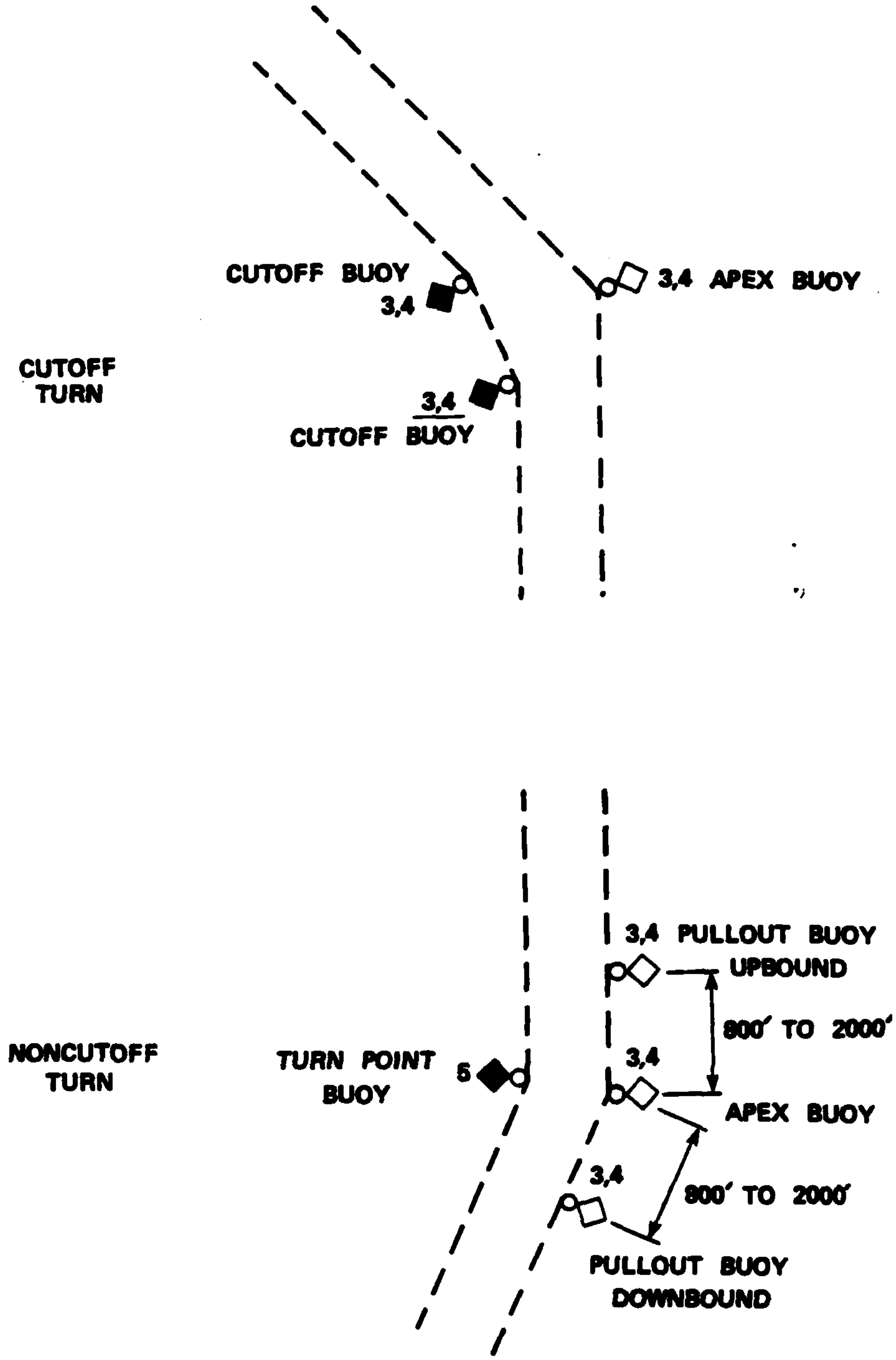


Figure 1-1. Turn Configurations and Possible Buoy Placements

buoys should be assigned a value of 4. The pilot must be able to judge the setting effect of that current.[9]

- The assumption here is that detection distance; the distance at which an aid will be detected given the meteorlogical visibility, the visible area of the aid, and its contrast against the background; is long enough to allow the pilot to see the next buoy. If this is true, no adjustment is necessary.[10]

- Given the numbers recommended here, no further adjustment is necessary for night operations.[11]

1.2.2 Buoys in the Recovery Region

Buoys in the recovery region are assigned a beginning number of 3.[12] For some conditions this 3 is increased to 4.

- For ships larger than 30,000 dwt the buoys should be assigned a 4.[13] Notice that the larger ship both extends the recovery region (see Appendix A) and increases the importance of buoys in that region.

- If there is no pullout buoy in the turn region to mark the crosstrack and alongtrack extent of the room available for the turn as illustrated in Figure 1-1, the next buoy should be 4. If the next buoy is one of a pair, or "gate," the buoy to the outside relative to the turn should be 4.[14]

- Buoy configuration as illustrated in Figure 1-2 is a factor:[15]

  - Gated, or paired, configurations with up to 1-1/4 nm spacing need no adjustment.

  - For staggered or alternate-side arrangements, with an alongtrack spacing above 5/8 nm, adjust to 4.

  - For one-side arrangements of any spacing, adjust to 4.

- Traffic extends the recovery region but requires no additional adjustment within that region.[16]

- Wind requires no additional adjustment.[17]

- Current requires no additional adjustment.[18]

- It is assumed that detection distance is long enough to see the next buoy or pair of buoys.[19]

1.2.3 Buoys in the Trackkeeping Region

Buoys in the trackkeeping region are assigned a beginning number of 1.[20] Additional points are added for conditions as follows:

- For winds of over 17 knots crossing the ships' path and gusting unpredictably, add 1.[21]

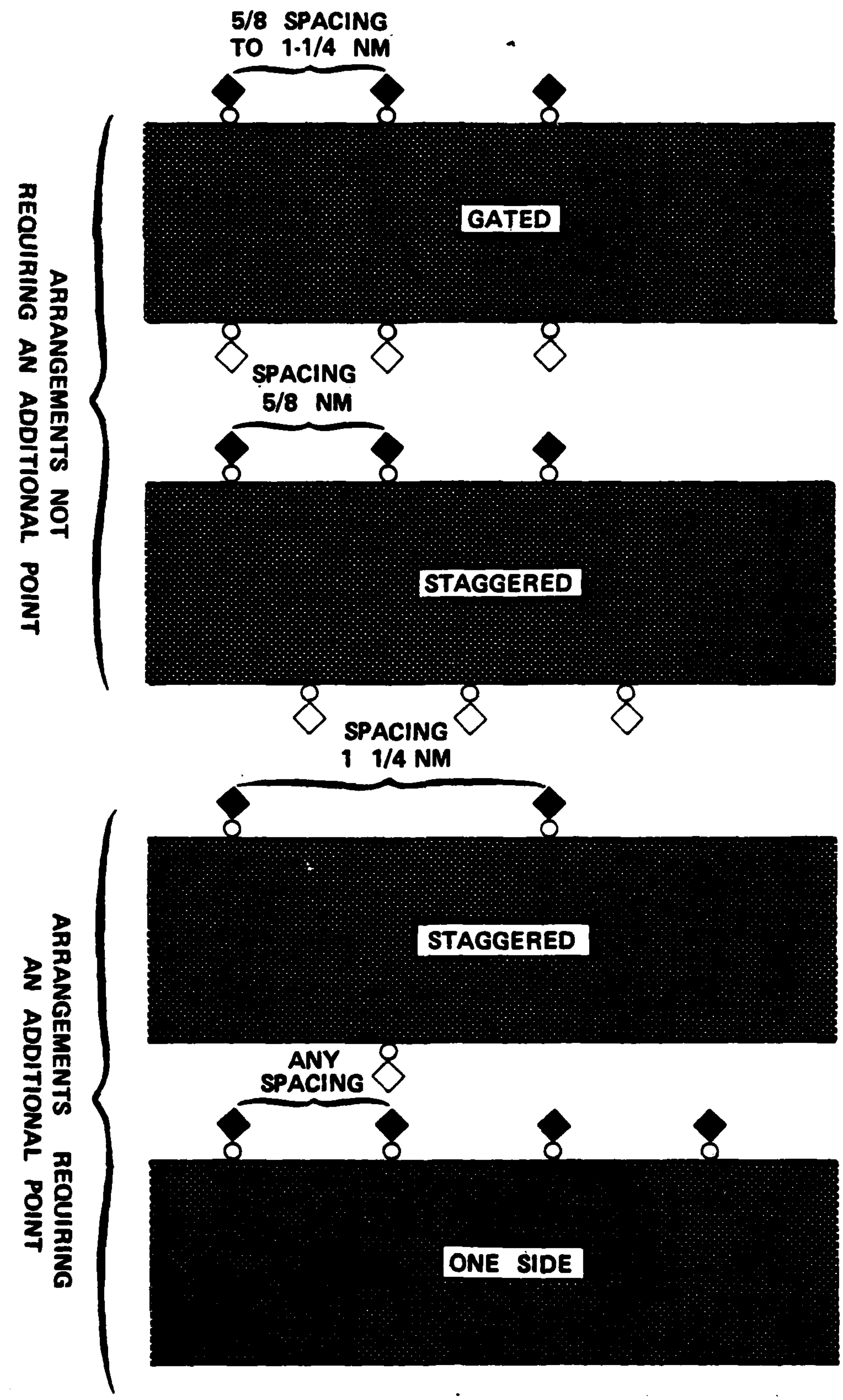


Figure 1-2. Alternate Straight Channel Buoy Arrangements

- Buoy configuration as illustrated in Figure 1-2 is a factor:[22]

  - Gated, or paired, configurations with up to 1-1/4 nm spacing need no adjustment.

  - For staggered, or alternate-side arrangements, with an alongtrack spacing above 5/8 nm, add 1.

  - For one-side arrangements of any spacing, add 1.

- For ships larger than 30,000 dwt, add 1.[23]

- Current extends the recovery region and its effect on the need for buoys is expressed in that way. No adjustment is required.[24]

- Traffic extends the recovery region and its effect on the need for buoys is expressed in that way. No adjustment is required.[25]

- As before, the recommendations here assume a detection distance long enough to see the next buoy. No adjustment is required.[26]

1.2.4 Adjusting Buoy Priorities for Range Lights

A choice as to whether a particular port should be marked with ranges, or buoys, or both, must be based on a number of factors. These include the relative cost and effort of installation, the relative reliability and cost and effort of maintenance, the detection distance and other environmental conditions to be expected, the importance that traffic maintain the exact center of the channel, the subjective preference of the users, and the objective precision of piloting performance that can be expected with alternate SRA designs. The consideration of all factors is the responsibility of the U.S. Coast Guard and beyond the scope of this manual. The special concern of this manual is the precision of piloting performance to be expected with the two types of aids. Ranges have the advantage in precision when finding and maintaining a track on the range axis. On the other hand, buoys have the advantage in usefulness for piloting tasks that require knowledge of the channel edges: for example, making turns and passing traffic.[27] The recommendations for buoy priorities assume that the buoys, for periods of short detection distances and for maneuvering, must be able to stand alone. Sections 1 and 2 of this manual are concerned almost entirely with piloting performance. Section 3 suggests techniques by which the Coast Guard can include other factors in the design or evaluation of aids to navigation.

It is recommended that when a range is present, buoys in the trackkeeping region be decreased in priority to a minimum of three, with the understanding that this lower value is appropriate only during conditions in which the ranges are always visible.

1.2.5 The Priorities of the Range Lights

The priorities for range lights themselves are divided only into "high" and "low." Two sets of factors determine the priority: the

adequacy of the buoy configurations, independent of the range; and the importance of ships' maintaining the exact axis of the range.

- The adequacy of the buoy configurations is established by the procedures of Appendices A and B. If the buoy configurations are adequate, the range lights may be assigned a "low" priority. Otherwise, they should be "high."[28]

- If it is essential that ships maintain the axis of the range; because of such conditions as an extremely narrow channel, large ships for the channel width, hazardous cargoes, dangerous shoals, or major crosscurrents; the range light priority should be "high," regardless of the adequacy of buoy configurations.[29]

1.3 AN ILLUSTRATIVE EXAMPLE

In Appendix A the processes described there - specifying conditions and dividing the channel into regions - were illustrated by application to the Baltimore Harbor approach. This example is continued here with the assignment of priorities to the buoys. These priorities are illustrated in Figure 1-3.

1. Turn Region. Starting with the noncutoff turn at the bottom, the turnpoint, "6C," is a 5. Because of traffic, the facing buoy, "5C," is a 4.

For Craighill Angle the principal buoys outlining the turn are 4, because of the high angle of turn, because of the larger ships, and because of traffic. The supplementary buoys (more than those shown in Figure 1-1) are 3.

2. Recovery Region. Because of the large ships, buoys in the recovery regions are 4. These include: "3C," "4C," "7C," "8C," "17C," and "18C."

The remaining buoys are "1C" and "2C" at the entrance to the channel. Because of the freedom to maneuver in the approach, these are considered recovery buoys. Because of large ship size and traffic, they are assigned 4.

3. Trackkeeping Region. There is no trackkeeping region.

4. Adjusting Buoy Priorities for Range Lights. The recovery buoys in the straight channel segments have been given an alternative value of 3 in consideration of the range lights with the understanding that this value holds only for periods of adequate detection distance.

5. The Priorities of the Range Lights. Because the buoy configurations are adequate for conditions and because there are no extreme conditions that make it necessary for ships to maintain the axis of the range, the lights have a "low" priority.

In summary, because of the operational requirements of large ships and traffic, the distribution of priorities is relatively restricted:

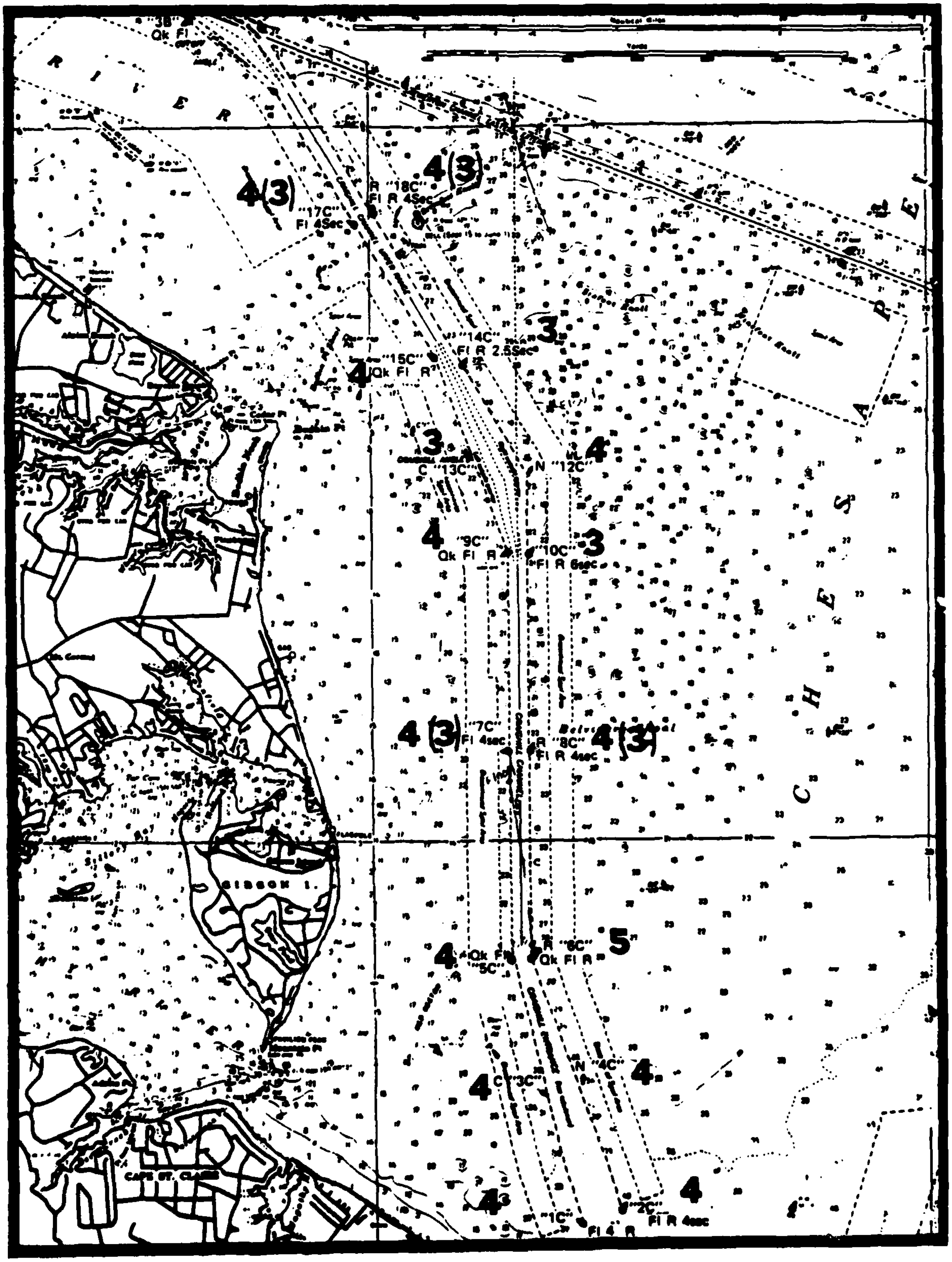


Figure 1-3. Maintenance Priorities for Baltimore Approach
(Chart 12278, October 11, 1980 With Additions)

there are buoys with priorities of 5, 4, and 3; there are none with priorities of 1 or 2. The buoys can function independently of the range lights.

EXPLANATORY NOTES FOR SECTION 1

1. This extremely general description of piloting technique is supported by discussions with pilots at both CAORF and Eclectech Associates.

2. The report by Bertsche and Mercer on major U.S. ports reported in Section 5 that a substantial percentage (34 percent) of turns of a variety of configurations are marked by one buoy.

3. The general level of 3 or 4 is selected here rather arbitrarily as less than the maximum of 5 but leaving some room for lower priorities. Whether a buoy is 3 or 4, however, is not arbitrary. The principal sources of comparisons for factors influencing the turn is CAORF Preliminary Performance Data, Volume 6, Section 2 which illustrates the interaction of angle of turn-by-turn configuration by number of buoys-by-day/night.

4. The report by Bertsche and Mercer on major U.S. ports reported in Section 5 that some small percentage of turns have a larger number of buoys than the three or four in Figure 1-1. Possibly these are very long turns. The illustrative example later in this section includes such a turn: Craighill Angle in the Baltimore approach. Until a few years ago it was marked by seven buoys (not all lighted).

5. The CAORF Preliminary Performance Data, Volume 6, Section 2 shows that performance was adequate in 15-degree one-buoy turns but not in 35-degree one-buoy turns.

6. Bertsche, Atkins, and Smith, Ship Variables Principal Findings, Section 4 reported a greater dependence on buoy density of performance with the 80,000 dwt ship. Section 5 of that report discusses the greater difficulty of the larger ship in making the turn.

7. a. The problem of traffic in the turn was not addressed in any of the simulator experiments.

   b. Cooper, Cook, and Marino, At Sea Data Collection, Section 2 showed that the pilots had a preference for passing traffic in Craighill Angle which is a very long, wide cutoff turn.

8. a. Smith and Bertsche, CAORF Principal Findings, Section 3.6 reports that crosswind in the straight segments has an effect on piloting that is counteracted by high buoy density.

   b. Bertsche, Atkins, and Smith, Ship Variables Principal Findings, Section 3 provides an analysis of wind effects in the straight segment in the earlier Channel Width experiments and provides data for the same conclusion: crosswind increases a need for buoyage.

c. Wind was included in the experimental scenarios as a within-scenarios variable. The findings reported here are only a preliminary exploration of the possible effects. There was no variation of wind in the turn. For the present, the cautious conclusion is that there is an effect.

9. a. Smith and Bertsche, CAORF Principal Findings, Section 3.5 reports the effect of crosscurrent on piloting. It is a larger effect than that of wind and is not as easily counteracted by buoyage.

b. Smith and Bertsche, Channel Width Principal Findings, Section 2 supports a conclusion similar to that described in 9a.

c. Current was included in the experimental scenarios as a within-scenarios variable. The findings reported here are only a preliminary exploration of the possible effects. There was no variation of current in the turn. For the present, the cautious conclusion is that there is an effect.

10. a. Smith and Bertsche, CAORF Principal Findings, Section 3.3 reports that detection distance longer than spacing was all that was needed in the straight segments. By extension, if detection distance is long enough to see all the buoys in the turn and pullout is present, longer detection distance should not make a difference.

b. CAORF Preliminary Performance Data, Volume 6, Section 2 shows turn performance differences that are explainable by a day/night difference and not by a detection range difference.

11. CAORF Preliminary Performance Data, Volume 6, Section 2 shows that night has its effect on the pullouts of 35-degree turns, but not on 15-degree turns. Since it has already been suggested that buoys outlining higher-angle turns be numbered 4, it is not necessary to make an adjustment for night.

12. a. Smith and Bertsche, Channel Width Principal Findings Report, Section 3 describes the relationship of straight channel performance to the buoyage. The data of that experiment is summarized in Table 1-2A. The relationships in that table are expressed in simplified form in Table 1-2B. The value, 3, for "maneuvering with perturbation," which represents performance coming out of the turn and settling on the centerline, was selected for a beginning value for the recovery region for the 30,000 dwt tanker.

b. The recovery from the turn was made with the crosscurrent effect which is described most thoroughly in Smith, Bertsche, and Williams, CAORF Presimulation Report. This current magnified the perturbing effect of the turn. No turn recoveries were evaluated without it. Conclusions drawn from the experimental recoveries are, thus, cautious with respect to a variety of recovery conditions.

TABLE 1-2A. STRAIGHT CHANNEL PERFORMANCE

Task	Mean Standard Deviation	Scenario Conditions: Staggered 5/8 nm Spacing	Gated 5/8 nm Spacing	Staggered 1-1/4 nm Spacing	Gated 1-1/4 nm Spacing
Trackkeeping without perturbation	Mean	4R*	7L	32L	0
	SD	22	37	52	34
Trackkeeping with perturbation	Mean	84R	40R	70R	76R
	SD	55	65	91	58
Maneuvering without perturbation	Mean	29R	12R	5L	7R
	SD	25	25	65	39
Maneuvering with perturbation	Mean	110R	81R	104R	90R
	SD	38	51	53	32

*Means are expressed as feet to the right or left of the centerline.

TABLE 1-2B. STRAIGHT CHANNEL VALUES

Task	Scenario Conditions: Staggered 5/8 nm Spacing	Gated 5/8 nm Spacing	Staggered 1-1/4 nm Spacing	Gated 1-1/4 nm Spacing
Trackkeeping without perturbation	1	1	2	1
Trackkeeping with perturbation	2	2	3	2
Maneuvering without perturbation	2	2	3	2
Maneuvering with perturbation	3	3	4	3

c. The recommendations for the recovery region are based primarily on pullouts from noncutoff turns. They may be unnecessarily long when applied to the less perturbing cutoff turn. However, notice that the length of the recovery region is measured from the turn apex, whatever the configuration of the turn. For a cutoff turn, the length of the cutoff subtracts from the total recovery region. This subtraction is an appropriate tradeoff: the longer the cutoff, the less perturbing the turn, and the shorter the effective recovery region.

d. The recommendations are based on a 500-foot channel. Smith and Bertsche, Channel Width Experiment supported the conclusion that no additional buoyage is necessary for an 800-foot channel - less might be possible. Narrower channels were never evaluated. Possibly narrow channels would make buoys more critical.

13. a. Bertsche, Atkins, and Smith, Ship Variables, Principal Findings Report, Section 4 documents the greater dependence of the 80,000 dwt ship on buoyage compared to the 30,000 dwt ship.

b. The recommendation for large ships is based on transits of the 80,000 dwt tanker in a 500-foot channel. The larger ship was never run in an 800-foot channel. Possibly with the 800-foot channel the larger ship would not require an adjustment.

14. Smith and Bertsche, CAORF Principal Findings Report, Section 4.7 illustrates the need for buoys on the outside of the turn for the pullout and recovery.

15. a. Smith and Bertsche, Channel Width Principal Findings, Section 3 documents the effect of buoy density on pilotage. The data is summarized in Table 1-2A and 1-2B. Notice the lowest buoy density condition, with a long-spaced, staggered arrangement, showed performance significantly worse than others.

b. Marino, Smith, and Bertsche, One-Side Channel Marking Principal Findings documents the deleterious effects on pilotage of low density arrangements. For tasks that require knowledge of the channel edges (turn pullout and recovery, finding a new track, and compensating for wind and current) one-side arrangements support inferior, even inadequate performance.

16. Smith and Bertsche, CAORF Principal Findings Report, Section 2 described performance passing a traffic ship with no crosswind or current. It was an easy problem with no dependence on buoyage. In Table 1-2A such a situation would be represented by the line "maneuvering without perturbation." Since no entry in this row is higher than the basic 3 for this region, no adjustment is recommended for such a situation. With a crosswind or crosscurrent, the traffic situation would be represented by the line "maneuvering with perturbation." The entries there are the basic 3 (except for the low density arrangements for which an adjustment has already been recommended) so no further adjustment is recommended.

17. a. Bertsche, Smith, and Atkins, Ship Variables Principal Findings Report, Sections 4 and 5 show that crosswind has its principal effect on large ships with rear houses. Since large ships are already given an adjustment to 4, no further adjustment is recommended here.

    b. There was no attempt made to separate the effect of ship size (maneuverability) from that of ship configuration in relation to the wind in any of the simulation experiments.

18. The basic value of 3 used for the recovery region was taken from those rows in Table 1-2B that assume "perturbation." A crosscurrent requiring a drift angle of 2 to 5 degrees is already accounted for. See footnote 12 in this sequence.

19. Smith and Bertsche, CAORF Principal Findings Report, Section 3.3 concludes that visibility beyond the next buoy makes no contribution to piloting performance.

20. Smith and Bertsche, Channel Width Principal Findings Report, Section 3 provides the primary support for this section. In Table 1-2B in the trackkeeping rows, there are values as low as 1 for trackkeeping in Leg 1 with following wind and current.

21. a. Table 1-2B shows values of 2 for trackkeeping with perturbation. These values come from Leg 2 after the crosstrack mean of the transits has returned to the centerline and where there is a crosstrack component to the wind of 17 knots.

    b. Smith and Bertsche, CAORF Principal Findings Report, Section 3.6 discusses the effect of crosswind on piloting. It is a relatively small effect - compared to current - and the adequate buoyage will allow the pilot and/or the helmsman to completely compensate for its effects. An extra point is given the buoys to obviate the effect of wind.

22. a. Table 1-2B shows values a point higher than the others for the low buoy density condition in all parts of the scenario or for all piloting tasks. Notice that crosswind and low buoy density together result in a 3.

    b. Marino, Smith and Bertsche, One-side Channel Marking Principal Findings Reports demonstrates that, even for trackkeeping, one-side marking is somewhat inferior to gated arrangements. A quantification of the degree of inferiority is possible by the methods of Section 3.

23. Table 1-2 is a summary of findings from the Channel Width experiment done with a 30,000 dwt ship. It is necessary to refer to Bertsche, Atkins, and Smith, Ship Variables Principal Findings Report, Section 4 and 5 extend these relationships to the 80,000 dwt ship. Piloting performance is poorer with the larger ship and high buoy density is

needed for merely adequate performance. Notice that the large ship, crosswind, and low buoy density result in a 4.

24. Current extends the recovery region as described in Appendix A and the footnotes for current. Since the beginning number for the recovery region is 3, this extension of the recovery region is equivalent to adding 2 points to the beginning 1 in the trackkeeping region. This implies that current is a greater effect than wind, which requires an adjustment of only 1. Such seems to be the case. The crosscurrent causes a displaced mean and an enlarged standard deviation as long as it lasts. This effect cannot be compensated for by high density of buoys as can the wind effect. The effect on performance is to keep the pilot "maneuvering," responding to his relationship to the channel edges, as long as the current lasts. This is especially true if the current changes over time or distance as it did in the experimental scenario. The effects of wind and current are discussed in Smith and Bertsche, CAORF Principal Findings, Section 3 and Smith and Bertsche, Channel Width Principal Findings, Section 2. They are further illustrated in the Preliminary Performance Data for either experiment.

25. Extending the recovery area is the equivalent of adding 2 to the value of the buoys. When it is necessary to choose an alternative track in the channel for passing or overtaking traffic, it is necessary to have a relatively precise knowledge of the channel edges. For this reason each buoy becomes more important than they would be for "trackkeeping," staying on track while approaching a short-turn destination.

26. Smith and Bertsche, CAORF Principal Findings Report, Section 3 concludes that detection distance to the next buoy is necessary, but detection distance beyond that is not helpful.

27. Marino, Smith, and Bertsche, Range Lights Principal Findings Report reports the superiority of the range lights, compared to buoys, for finding and maintaining a track on the axis of the range. Even for this task, at which range lights potentially excel, the sensitivity of the range (the ease of perceiving crosstrack movement) is a factor, with a low sensitivity range inferior to a parsimonious buoy configuration. Even with the high sensitivity range, turning and trackkeeping off the axis of the range was inferior to that with buoys. It should be pointed out that the pilots reported confidence in the ranges even when their performance with them was objectively poor.

28. The recommendations that result from the application of Appendices A and B are designed to stand alone without range lights. This independence is based on two assumptions: first, that ranges are not useful in restricted detection distances when the buoys must be adequate alone; and, second, that ranges need to be augmented by buoys for turning and maneuvering under a wide variety of conditions. The usefulness of ranges is discussed in Marino, Smith, and Bertsche, Range Light Principal Findings Report.

29. In Marino, Smith, and Bertsche, Range Light Principal Findings, Section 2, it is reported that a highly sensitive range is superior to even high density buoy arrangements for the specific task of finding and maintaining the axis of the range.

Section 2

THE EVALUATION OF THE ADEQUACY OF SHORT-RANGE AID SYSTEMS

2.1 INTRODUCTION AND APPLICATION

The overall purpose of this manual is to relate channel or harbor conditions to the aid to navigation systems needed to provide adequate performance. This manual is based on a body of performance data collected on a shiphandling simulator designed specifically for the project. The unique characteristic of the recommendations of the manual is that they are based on performance data collected under the needed conditions.[1]

Performance data were collected relating sets of channel conditions to alternative configurations of short-range aids (buoys or range lights) and radio aids displays. The logic of the project was that channel conditions (physical channel dimensions, environmental conditions, ship characteristics, and operational requirements) combined to form a problem that will be solved by the aids to navigation system (the number and placement of aids available). Generally speaking, the more difficult the problem, the greater the number of aids required and the more critical their placement. Conversely, some aid to navigation systems (usually sparse, low-buoy density configurations) are themselves problems. They encourage imprecise and variable piloting techniques and are adequate only for undemanding channel conditions. The program of pairing channel conditions with alternative aid configurations made it possible to specify that for a given set of conditions, a given aid configuration is "adequate," "inadequate," or "redundant." By "adequate" is meant that the observed piloting performance was as precise as any observed in the project and/or was the best that was observed under the specified channel conditions. By "inadequate" is meant that the observed performance was less precise and significantly poorer than observed performance under similar conditions with more aids. By "redundant" is meant that, while performance is adequate and precise, similarly adequate and precise performance was observed under those conditions with <u>fewer</u> aids.[2]

The ability to evaluate short-range aid to navigation systems for the conditions in which they appear has a number of applications.

1. The evaluation of existing configurations to identify weaknesses[3] or excessive redundancies[4] is one application. For this application one should:

- determine adequate configuration requirements
- determine discrepancies with existing configurations
- suggest changes to eliminate the discrepancies. Such a process is illustrated by example in Section 2.3

2. The recommendation for aid to navigation systems for new channels is a possible application of this section.

3. Preparation for the techniques of risk management and cost/benefit analysis described in Section 3 and Appendix C is another application. Those techniques are meant to apply only to adequate configurations, and not to those that are inadequate or do not conform to the standards of Appendix B.

2.2 PROCEDURE FOR ESTABLISHING ADEQUACY OF SRA

For this application the working instructions are entirely in two appendices. Appendix A provides instructions for specifying the channel conditions for which visual aids to navigation are to be arranged and for dividing the channel into regions with varying demand for aids. Appendix B provides instructions for selecting the number and placement of aids that will provide adequate performance for those conditions, region by region.

2.3 AN ILLUSTRATIVE EXAMPLE

The principal application in this section is illustrated here using the entrance channel to Tampa Bay.[5] The discussion begins with the process in Appendix B for specifying adequate configurations for the conditions. It continues with a comparison with existing configurations and suggests changes.

2.3.1 The Turn Region in Mullet Key Channel

An excerpt from the chart for the approach to Tampa Bay appears as Figure 2-1. On this chart the turn and recovery regions have already been outlined, according to the directions in Appendix A. Only one turn region is outlined, the cutoff turn in Mullet Key just below and to the left of the bridge. The conditions that will be considered are reported in Figure 2-2. By the rules of Table B-1 in Appendix B, this turn should be marked with three buoys: one at each edge of the cutoff and one at the apex.

Inspection of Figure 2-1 shows this turn is at present marked with a gated pair of buoys Such a configuration is inadequate for cutoff turns (see Figure 2-2 for the only two-buoy configuration which is adequate for cutoff turns). The existing configuraton does not show the pilot the edges of the cutoff nor the orientation of the channel leg into which he is to exit the turn. There is a range light (Cut A Range), that is detectable approximately 95 percent of the time in this particular harbor, marking the orientation of the second leg. Since this manual is based on data that show ranges to be of limited value for the actual turn maneuver, three buoys are suggested for the turn region as shown in Figure 2-3.

2.3.2 The Recovery Region of Mullet Key Channel

Mullet Key Channel is a recovery region both in relation to the channel entrance and outbound from the turn. The conditions in that recovery region are reported in Figure 2-4. According to the rules of Table B-4 in Appendix B, an adequate configuration for traffic in a

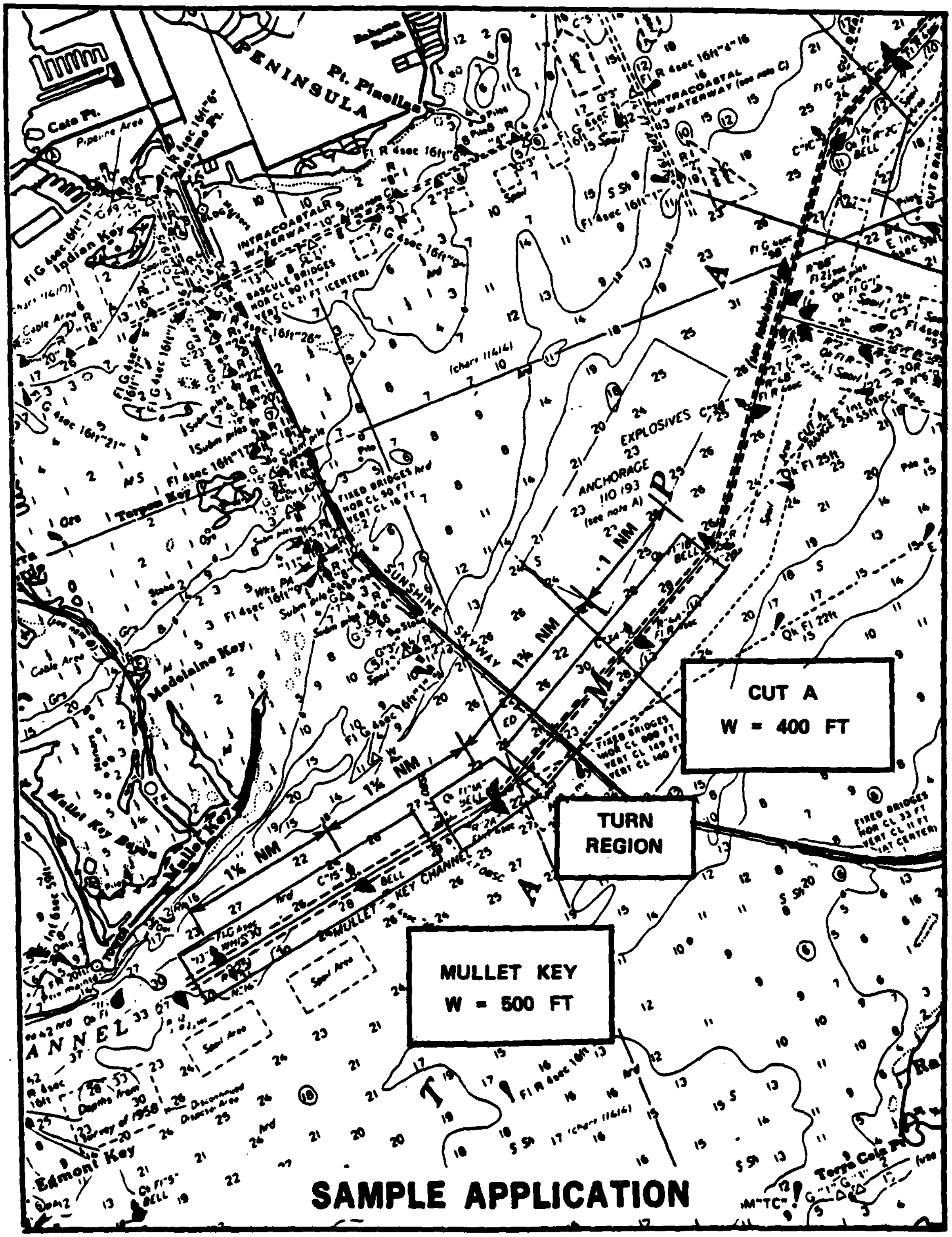


Figure 2-1. Conditions in Mullet Key and Cut A Channels, Tampa Bay
(Chart 11414, March 28, 1981, with additions)

TURN REGION IDENTIFICATION FORM NNN

1. TURN NAME AND LOCATION Mullet Key, Tampa Bay	2. CHART NO. 11414
3. LATITUDE AND LONGITUDE OF TURN APEX	

CHANNEL AND ENVIRONMENTAL PARAMETERS

4. ENTER CHANNEL WIDTH (FEET)	W= 500	FT
5. ENTER MAXIMUM CROSS CURRENT COMPONENT (KNOTS)	VX= .5	KTS
6. ENTER MAXIMUM WIND VELOCITY (KNOTS)	VW= 20	KTS

DESIGN VESSEL PARAMETERS

7. ENTER SHIP TYPE AND DWT	Tanker / 30K	
8. ENTER MINIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMIN= 6	KTS
9. ENTER MAXIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMAX= 12	KTS
10. ENTER SHIPS LENGTH (FEET)	L= 596	FT
11. ENTER SHIPS BEAM (FEET)	B= 84	FT

SRA DESIGN PARAMETERS (CIRCLE ONE)

12. AN DETECTION DISTANCE	LESS THAN 1 NM (RADAR)	GREATER THAN 1 NM (VISUAL)
13. DAYLIGHT CONDITIONS	DAY	NIGHT, DUSK OR DAWN
14. TURN CONFIGURATIONS	NONCUTOFF	CUTOFF
15. TURN ANGLE	0 TO 20 DEG	20 TO 40 DEG
	GREATER THAN 40 DEG	
16. TRAFFIC	ONE WAY	TWO WAY

DT =	DETERMINE FROM TABLE A1
	17 END TO (END) OF CUTOFF

ADEQUATE NUMBER OF TURN MARKINGS (CIRCLE ONE)

SRA CONFIGURATION				
	4 BUOYS	3 BUOYS	2 BUOYS	1 BUOY

ADEQUATE PLACEMENT OF TURN MARKINGS

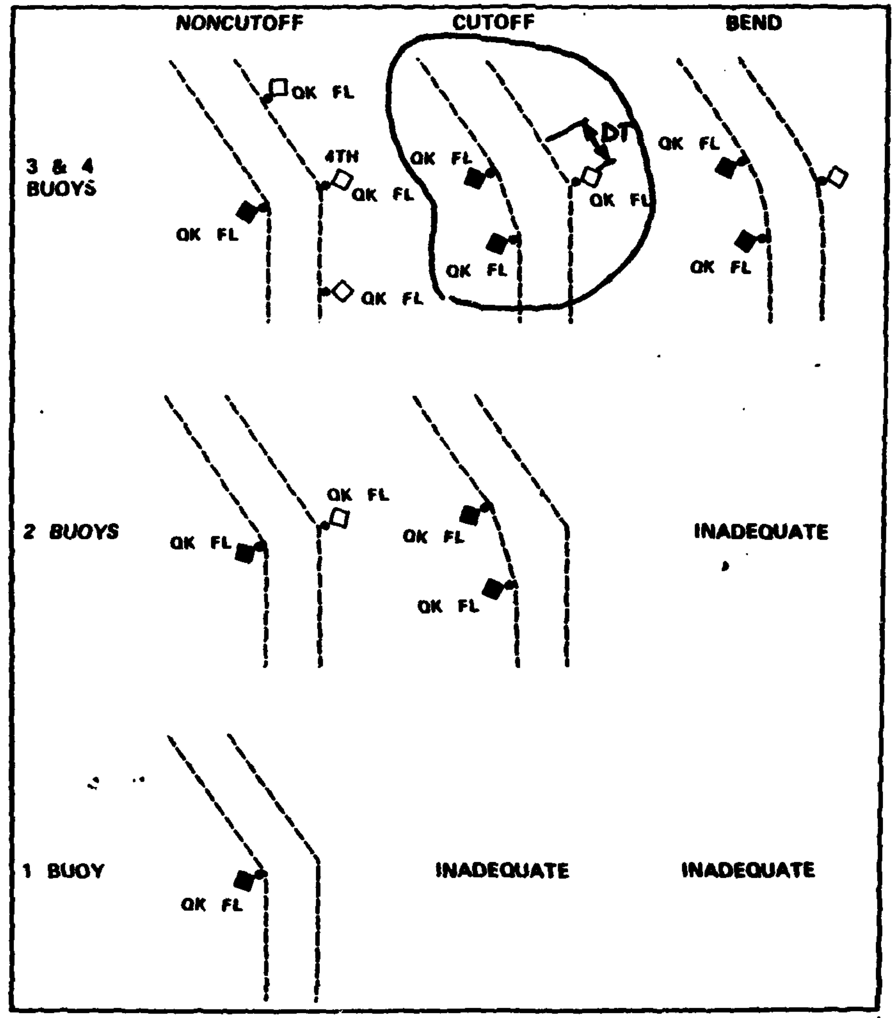


Figure 2-2. Sample Determination of Adequate Markings for Cutoff, 19-Degree Turn Between Mullet Key and Cut A Channels

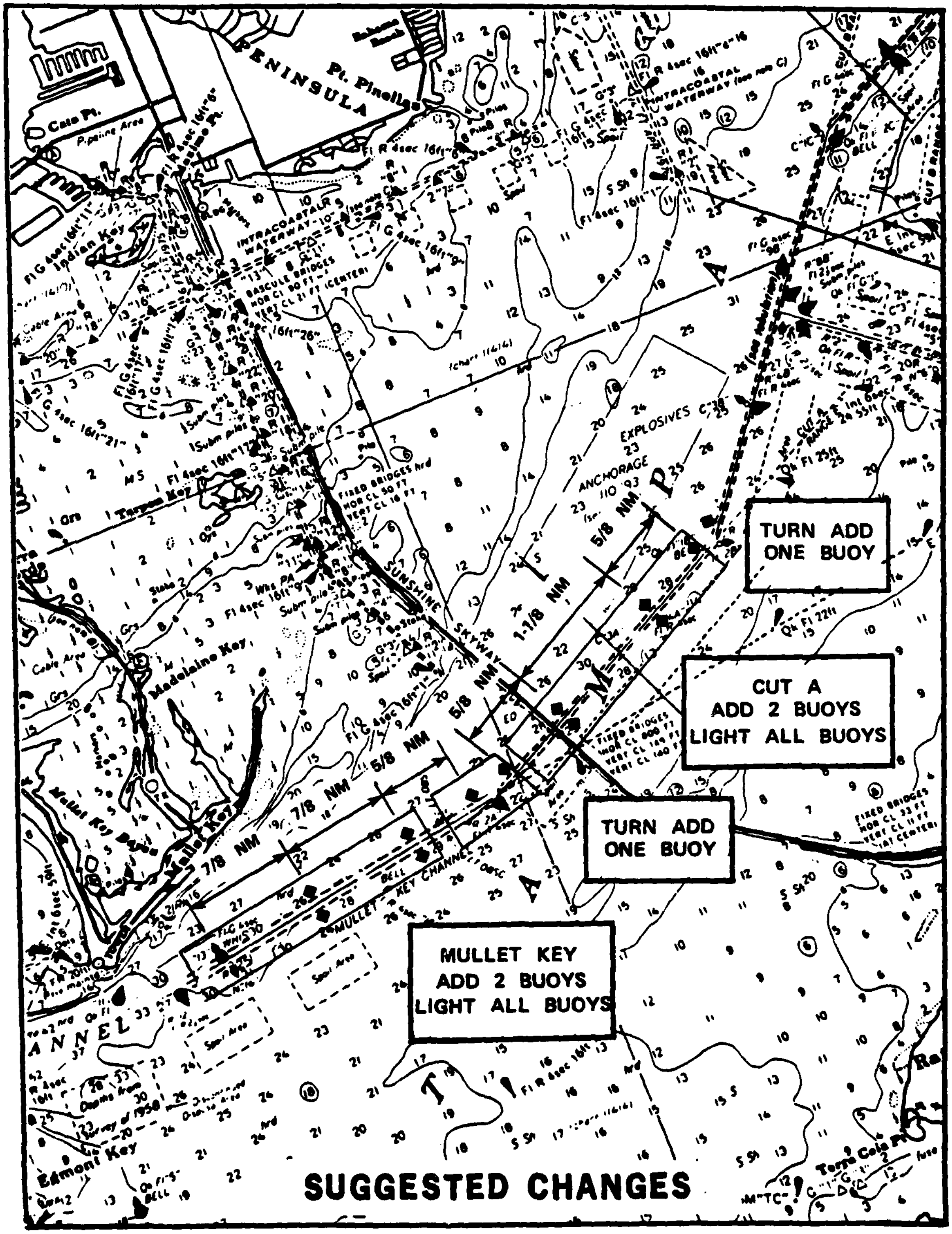


Figure 2-3. Recommended Buoy Configurations for Mullet Key and Cut A Channels (Chart 11414, March 28, 1981, With Additions)

RECOVERY REGION IDENTIFICATION **FORM 000**

1. TURN NAME AND LOCATION	2. CHART NO.
Mullet Key Tampa Bay	11414
3. LATITUDE AND LONGITUDE OF REGION MIDPOINT	

CHANNEL AND ENVIRONMENTAL PARAMETERS

4. ENTER CHANNEL WIDTH (FEET)	W= 500	FT
5. ENTER MAXIMUM CROSS CURRENT COMPONENT (KNOTS)	VX= 0	KTS
6. ENTER MAXIMUM WIND VELOCITY (KNOTS)	VW= 20	KTS

DESIGN VESSEL PARAMETERS

7. ENTER SHIP TYPE AND DWT	Tanker / 30K	
8. ENTER MINIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMIN= 6	KTS
9. ENTER MAXIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMAX= 12	KTS
10. ENTER SHIPS LENGTH (FEET)	L= 596	FT
11. ENTER SHIPS BEAM (FEET)	B= 84	FT

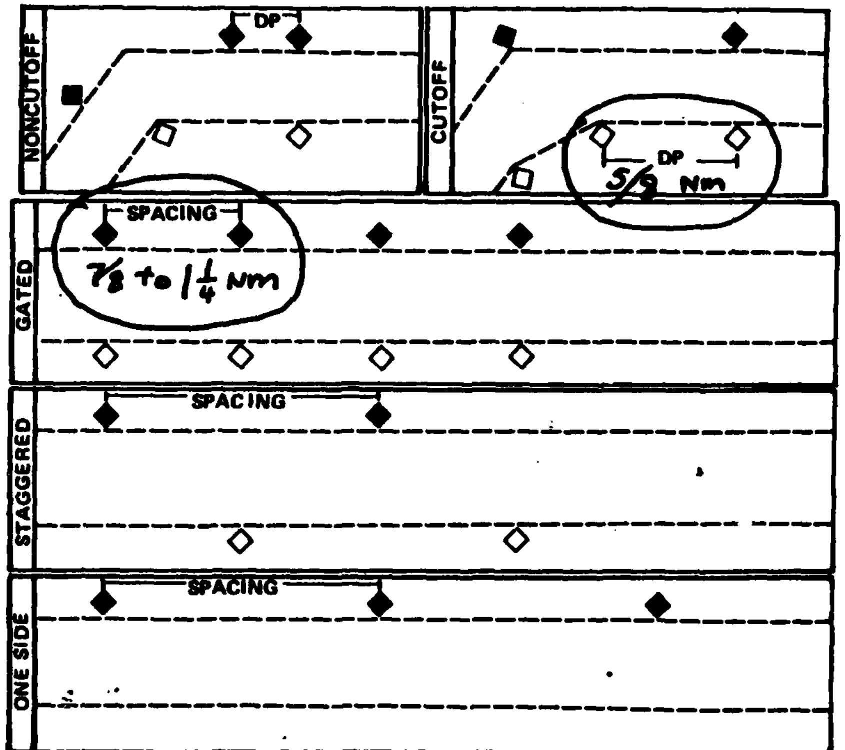
SRA DESIGN PARAMETERS (CIRCLE ONE)

12. AN DETECTION DISTANCE	LESS THAN AN SPACING (RADAR)	GREATER THAN AN SPACING (VISUAL)
13. DAYLIGHT CONDITIONS	DAY	NIGHT, DUSK OR DAWN
14. TRAFFIC	ONE WAY	TWO WAY
15. MAX EXPECTED DRIFT ANGLE	TAN^{-1}(LINE 5 / LINE 8) = 0 / 6	DA = 0 DEG

DR =	DETERMINE FROM TABLE A.2
	16 Turn (to Turn)

RECOVERY REGION ADEQUATE CHANNEL MARKING (CIRCLE ONE)

MAXIMUM DISTANCE FROM TURN PULLOUT OR CUTOFF BUOY TO FIRST BUOY	D.P.≤3/8 NM	D.P.≤5/8 NM
SRA CONFIGURATION	GATED / HIGH SENS. RANGE	STAGGERED / ONE SIDE / LOW SENS. RANGE
AN SPACING	SHORT 5/8 TO 7/8 NM	LONG 7/8 TO 1 1/4 NM



RANGES	HIGH SENSITIVITY	LOW SENSITIVITY
	$3.0 < K < 10.0$*	$0.5 < K < 1.0$
	$2 < X_Q < 6$ FT*	$25 < X_Q < 40$ FT

*SEE COAST GUARD PUBLICATION 388 FOR CALCULATION OF THE VALUES OF LATERAL SENSITIVITY K AND CROSSTRACK POSITION X FOR THE Θ_Q DISPLACEMENT (i.e., X_Q).

Figure 2-4. Conditions and Adequate Configuration for the Recovery in Mullet Key, Tampa Bay

500-foot wide channel is long-spaced gates. Table B-3 defines long-spaced gates for a 500-foot channel as being spaced at 5/8 nm for the first gate and up to 1-1/4 nm for subsequent gates. An additional problem is the inclusion of unlighted buoys (N"14" and C"15") in the configuration. These are not useful for night operations. The nighttime configuration here is very sparse, very long-spaced, beyond anything recommended as adequate. This aid configuration requires serious reconsideration. A possible adequate configuration is shown in Figure 2-3. In Section 3 this example is compared with alternatives by use of the relative risk factors.

2.3.3 The Recovery Region of Cut A Channel

There is a second recovery region outlined on Figure 2-1: Cut A Channel. The conditions for this region are reported in Figure 2-5. Notice this channel leg differs from the first in being only 400 feet wide. As in the first segment in Section 2.3.2, the recommendation is for long-spaced gates as adequate. By the definition of Table B-3, this means 5/8 nm to the first gate and up to 1-1/4 for subsequent gates.

Inspection of Figure 2-1 shows longer spacing than that recommended. The first gate inbound from the turn is at 1-3/4 nm. This spacing, longer than any recommendation in the manual, is especially long in relation to the narrowness of the channel. During that 1-3/4 nm distance, the channel passes under the Sunshine Skyway Bridge, which is potentially an aid or a hazard. The piers present an 800-foot opening through which the 400-foot channel passes. The research on which this manual is based showed that wider channels result in a wider band of tracks. To restate that finding in terms of the piloting process, the precision with which the pilots selects his crosstrack position depends on the horizontal distance between the aids he sees. This means that the very wide opening between the piers will not encourage precise piloting in that narrow channel. On the balance the bridge is a hazard, as shipping is a hazard to the bridge. Cut A Range is visible under the bridge, in an area where the detection distance is sufficient for its use 95 percent of the time. If the detection distance is long, if the ship has made the turn successfully, and if there is no traffic to keep it off the axis of the range; that range will enable him to bring the ship to the center of the channel. Because it is critical that the ship recover from the turn under all conditions before pasing under the bridge, the range may not be sufficient. Additional weakness in this already sparse configuration is an unlighted buoy (C"3A"), which means that at night with restricted detection distance, there is only one buoy marking that segment. Additional marking should be considered for this segment: at least a gate to guide recovery between the turn and the bridge as in Figure 2-3. This configuration is compared to alternatives in Section 3 using the relative risk factors.

RECOVERY REGION IDENTIFICATION

FORM 000

1. TURN NAME AND LOCATION Cut A, Tampa Bay	2. CHART NO. 11414
3. LATITUDE AND LONGITUDE OF REGION MIDPOINT	

CHANNEL AND ENVIRONMENTAL PARAMETERS

4. ENTER CHANNEL WIDTH (FEET)	W= 400 FT
5. ENTER MAXIMUM CROSS CURRENT COMPONENT (KNOTS)	VX= 0 KTS
6. ENTER MAXIMUM WIND VELOCITY (KNOTS)	VW= 20 KTS

DESIGN VESSEL PARAMETERS

7. ENTER SHIP TYPE AND DWT	TANKER / 30 K
8. ENTER MINIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMIN= 6 KTS
9. ENTER MAXIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMAX= 12 KTS
10. ENTER SHIPS LENGTH (FEET)	L= 596 FT
11. ENTER SHIPS BEAM (FEET)	B= 84 FT

SRA DESIGN PARAMETERS (CIRCLE ONE)

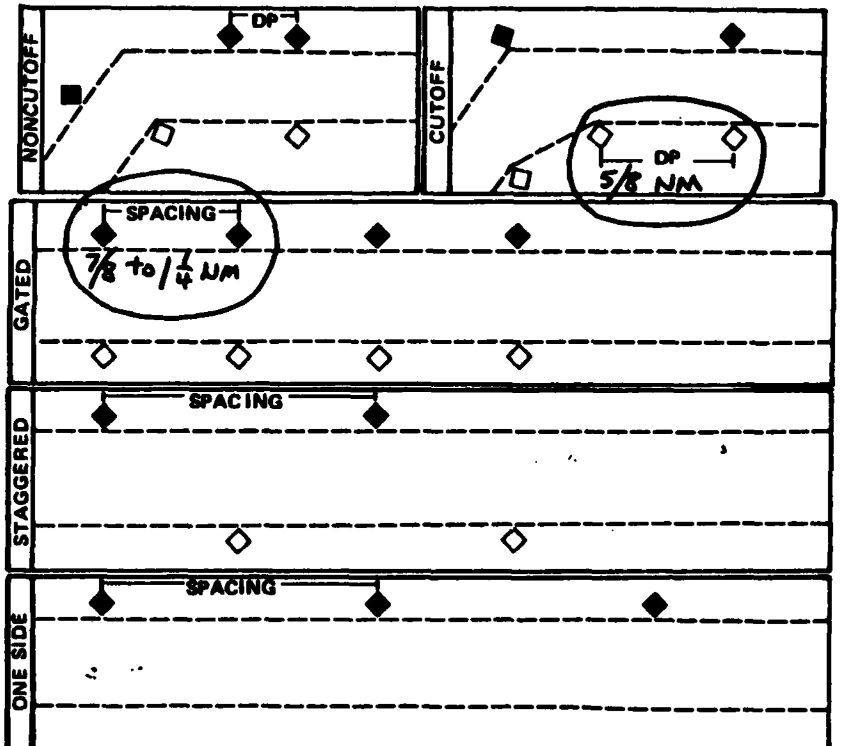
12. AN DETECTION DISTANCE	LESS THAN AN SPACING (RADAR)	GREATER THAN AN SPACING (VISUAL)
13. DAYLIGHT CONDITIONS	DAY	NIGHT, DUSK OR DAWN
14. TRAFFIC	ONE WAY	TWO WAY
15. MAX EXPECTED DRIFT ANGLE TAN^{-1}(LINE 5 / LINE 8) = 0 / 6		DA = 0 DEG

DR = DETERMINE FROM TABLE A.2 — 16 TURN TO TURN

Figure 2-5. Conditions and Adequate Configurations for the Recovery Region in Cut A Channel, Tampa Bay

RECOVERY REGION ADEQUATE CHANNEL MARKING (CIRCLE ONE)

MAXIMUM DISTANCE FROM TURN PULLOUT OR CUTOFF BUOY TO FIRST BUOY	D.P.≤3/8 NM		D≤5/8 NM
SRA CONFIGURATION	GATED	STAGGERED	ONE SIDE
	HIGH SENS. RANGE		LOW SENS. RANGE
AN SPACING	SHORT 5/8 TO 7/8 NM		LONG 7/8 TO 1 1/4 NM



RANGES	
HIGH SENSITIVITY	LOW SENSITIVITY
3.0< K <10.0*	0.5< K <1.0
2< Xa <6 FT*	25< Xq <40 FT

*SEE COAST GUARD PUBLICATION 398 FOR CALCULATION OF THE VALUES OF LATERAL SENSITIVITY K AND CROSSTRACK POSITION X FOR THE Θ_a DISPLACEMENT (i.e., X_a).

EXPLANATORY NOTES FOR SECTION 2

1. The "body of performance data" is described in:
   - Smith and Bertsche, CAORF Principal Findings.
   - Smith and Bertsche, Channel Width Principal Findings.
   - Bertsche, Atkins, and Smith, Ship Variables Principal Findings.
   - Marino, Smith, and Bertsche, One-Side Channel Marking Principal Findings.
   - Marino, Smith and Bertsche, Range Light Principal Findings.

   A number of related and support reports are also cited where relevant.

2. The logic of this section begins with the selection of one set of experimental conditions as a "standard." The selected conditions were a 35-degree noncutoff turn, a 1-1/2 nm detection distance with daytime conditions, a 30,000 dwt ship transiting at 6 knots, three turn buoys, and short-spaced, gated buoys in the straight segment. This is the highest density of buoys that appeared in the project, referred to elsewhere as "perfect information." These conditions appeared or were approximated several times.

   a. In the CAORF experiment that set of conditions must be examined piecemeal because of the fractional design (see the Principal Findings Report, page 17).

   b. In the Channel Width experiment it appears as Scenario 2.

   c. In the Ship Variables experiment, it appears as Scenario 5. Performance in this replication was slightly better than that in the Channel Width experiment: in Leg 2 the ship had settled by the second gate rather than the third. This difference was attributed to the more unpredictable wind in the Channel Width experiment.

   Other conditions considered in the project were usually compared to the standard set of conditions, either statistically or logically. Where similar perfomance was achieved with fewer buoys for a given set of conditions, those lower-density configurations were accepted. For example, in the Channel Width experiment the long-spaced, gated condition provided performance as good (except for the wind in Leg 2) as did the short-spaced gates; and is, therefore, considered adequate here. This lower-buoy-density condition was used as a standard in the one-side experiment as an appropriate challenge to the one-side channel marking conditions. (Leg 2 performance in this latter experiment with less wind perturbation verified the hypothesis that pilot performance in the Channel Width experiment was responding to wind.) Where fewer buoys provided poorer performance, the lower level of buoyage was not accepted. For example, in the Ship Variables experiment the 80,000 dwt tanker showed poor performance under low-buoy-density conditions. Therefore, for larger ships a higher level of buoy density is recommended.

Early in the project, there was commitment to evaluate as many variables as possible as parsimoniously as possible by emphasizing "main effects." That is to say, by comparing two values of a variable under limited combinations of related conditions. For example, 500- and 800-foot channels are compared with only two aid configurations and one size of ship. This strategy resulted in the evaluation of a great many variables but it also meant that specific combinations are not always available. Missing combinations are mentioned in other footnotes.

3. An example of an analysis of an existing system for weaknesses was done earlier in the project by Smith and Gaffney on Tampa Bay.

4. It is unlikely that many redundancies will be discovered with the manual as it now stands. This is true for a number of reasons.

   a. The experimental scenario (see CAORF Presimulation report or any subsequent presimulation report) deliberately confounded the turn pullout with crosscurrent to evaluate the most difficult version of a turn and ensure a safety margin in turnmarking recommendations. The recovery region, too, is affected by the crosscurrent. There was no examination of an abrupt turn, or the recovery from one, without this additional perturbation.

   b. The instructions to the pilot to stay on the centerline of the channel meant that differences were found (as was intended) among conditions that might have resulted in undistinguishable performance if the pilot had been allowed greater latitude.

   c. A factor that did not affect the thoroughness of recommended marking was the lack of radar. While many pilots said they would have used the radar to inspect the whole channel or harbor; under the experimental conditions of 3/4 or 1-1/2 nm detection distance, they would have made little use of it for the moment-to-moment decisions that contributed to measured performance.

   d. Ranges would have affected performance in some parts of the scenario under longer detection distances. (See Range Light Principal Findings Report.) But the experimental conditions were run under detection distances too short (3/4 or 1-1/2 nm) to use ranges. Consequently, the recommendations here are adequate for detection distances too short for ranges.

   e. The assumption that traffic extends the recovery region minimizes the incidents of trackkeeping regions that have less need for aids.

   f. Often, when specific combinations of conditions needed for conclusions were unavailable, a conservative or cautious extrapolation was made.

5. Tampa Bay, Southern Part, Florida, United States -- Gulf Coast, National Oceanic and Atmospheric Administration, Number 11414, March 28, 1981.

Section 3

THE APPLICATION OF RISK MANAGEMENT AND COST/BENEFIT IN THE DESIGN OF AID TO NAVIGATION SYSTEMS

3.1 INTRODUCTION

It is hypothesized that the safety of navigation in a narrow waterway will increase with the addition of more aids to navigation. Piloting performance data, support this relationship with the qualification that there is eventually reached a point where the addition of more aids to navigation will no longer significantly improve performance. There exists also the situation where the safety of navigation is adequate given a less than maximum density configuration and that the addition of ANs is not beneficial from a cost point of view. These relationships suggest two approaches for designing aids to navigation systems. One approach applies "risk management" techniques to AN system design. The other approach applies "cost/benefit" techniques to AN system design. Both approaches require the quantification of the risk of an accident as a function of the AN system design.

3.2 QUANTIFICATION OF THE RISK OF AN ACCIDENT

A very basic assumption of the program is that there exists a dependent relationship between the risk of accidents and the aid to navigation system. The better the AN system design, the lower the risk of accidents. The relationships of aids to the pilot's ability to stay inside the channel and avoid grounding is most straightforward and will be emphasized in the following discussion. But it is assumed that the design of aid systems, by the same principles, is also related to other types of accidents: that is, collisions and rammings. The pilot's ability to avoid accidents (collisions, rammings, and groundings) depends (not entirely, of course) on the aid system and its effectiveness in enabling him to make accurate and timely judgments of his position, velocity, and acceleration. In avoiding groundings, he must be able to make these judgments relative to the edges of the channel. In this process, the channel edge itself is not visible and the aid system (whether visual aids, radar, radio aids, or some combination) is all he has. In avoiding collisions and rammings the pilot must make his judgments relative to some moving or fixed object. The object to be avoided serves the function of an aid, but is not sufficient under all conditions in restricted waterways. The assumption is that an aid system that enables the pilot to assess his status plays a part in avoiding any type of accident.

Quantification of this relationship has previously been difficult due to the low occurrence of accidents relative to the number of transits (typically one accident for every 10,000 transits). Additionally, accident statistics could not be correlated to AN system designs because of the large number of factors contributing to the accident, such as human error, visibility, light, traffic, etc.

There exists, however, a set of piloting performance data which can be used to provide a "relative" indication of the risk of an accident as a function of AN system design. This data was compiled on a shiphandling simulator designed specifically to quantify the relationships between AN system designs and the risk of accidents. The "relative" characteristic of this data must be stressed in that the data are indicative of the differences in the risk of accidents as a function of alternate AN system design characteristics. Too few samples were run on the simulator to attempt to predict occurrences on the order of one every 10,000 transits.

The measure derived to quantify the relative risk of accidents is the "relative risk factor." This factor represents an estimate of the probability that a portion of the ship will cross a channel edge. It is based on an assumption that ship tracks are normally distributed about a mean track. It is suggested that the relative risk factor is directly proportional to the probability of grounding and that changes in the relative risk factor are proportional to changes in the actual probability of grounding:

$$RRF = (K)(PG) \qquad (3.1)$$

where:

RRF: relative risk factor
PG: probability of grounding
K: correction factor

Given these assumptions if the relative risk factor is increased by a multiple of 10 with increased buoy spacing, then it is assumed the actual probability of grounding will be increased by a multiple of 10 also.

The relative risk factor, although not a direct measure of the probability of an accident, can be satisfactorily applied to the design of AN systems when one design is being compared to another. AN designs which achieve a minimum relative risk factor can be assumed to provide the maximum safety possible relative to other AN designs. AN designs which achieve relative risk factors equivalent to those for existing channels can be assumed to exhibit the same safety record as the existing channel. AN configurations which are either excessive or inadequate can be identified and corrected based on the comparison of the relative risk factors associated with each configuration.

The sensitivity of the relative risk factor to increased density of aids to navigation can be used to optimize AN configurations with regard to cost/benefit analyses. The increased cost of AN systems can be equated to the reduction in the relative risk of accidents and associated decrease in the costs attributed to accidents.

Each of the above design approaches is described in this section of the manual.

3.2.1 Derivation of the Relative Risk Factor

The relative risk factor (RRF) is taken to be the sum of the probabilities that the port or the starboard extreme points of the ship will exceed the channel edge during a transit. These probabilities are calculated on the assumption that ship tracks will be normally distributed to either side of a mean track in accordance with the standard deviation of the ship's track. Data defining the mean track and the standard deviation of the tracks as a function of aids to navigation system design are taken from experiments conducted on the ship simulator.

The probabilities required are derived by determining the number of standard deviations which lie between the extreme points of the ship and the channel boundary and then calculating the area under the normal distribution curve beyond this point. These calculations are made when the ship is properly oriented to account for the mean crosstrack displacement of the ship's center of gravity (CG) and the required drift angle due to a crosscurrent component. These relationships are shown diagrammatically in Figure 3-1. The areas under normal distribution curves which fall beyond the channel edge are shown in Figure 3-2. The relative risk factor is the sum of these two areas.

$$RRF = PS + PP \tag{3.2}$$

where:

- PS: probablity the extreme starboard point will cross the starboard channel edge
- PP: probability the extreme port point will cross the port channel edge

The values for the RRF are judged to be conservative estimates of the probability of grounding. That is, if they are biased, they are biased in a safe or cautious direction: in this case, they may be larger than they should be and may over-estimate the risk. There are a number of reasons why any bias here is in a conservative direction. The first is the assumption of normal distribution. The standard deviations and mean displacement values were derived based on a piloting strategy of staying on the channel centerline. It is believed that when pilots purposefully maneuver close to the channel edge (e.g., when passing traffic ships, setting up for a turn, crabbing in a large crosscurrent, etc.), they reduce the variability of ship's tracks (standard deviation) particularly in the direction of the channel edge. Thus, some form of truncated distribution is more likely representative of actual piloting performance when the ship is near the channel edge. The data are presently not sufficient to determine the exact distribution, so the assumption of the normal distribution is made as a conservative one. Given that conservative estimates of the RRF are used, and given that proportional relationships between the RRF and the actual probability of grounding are assumed; these values are also conservative estimates of the actual probability of grounding.

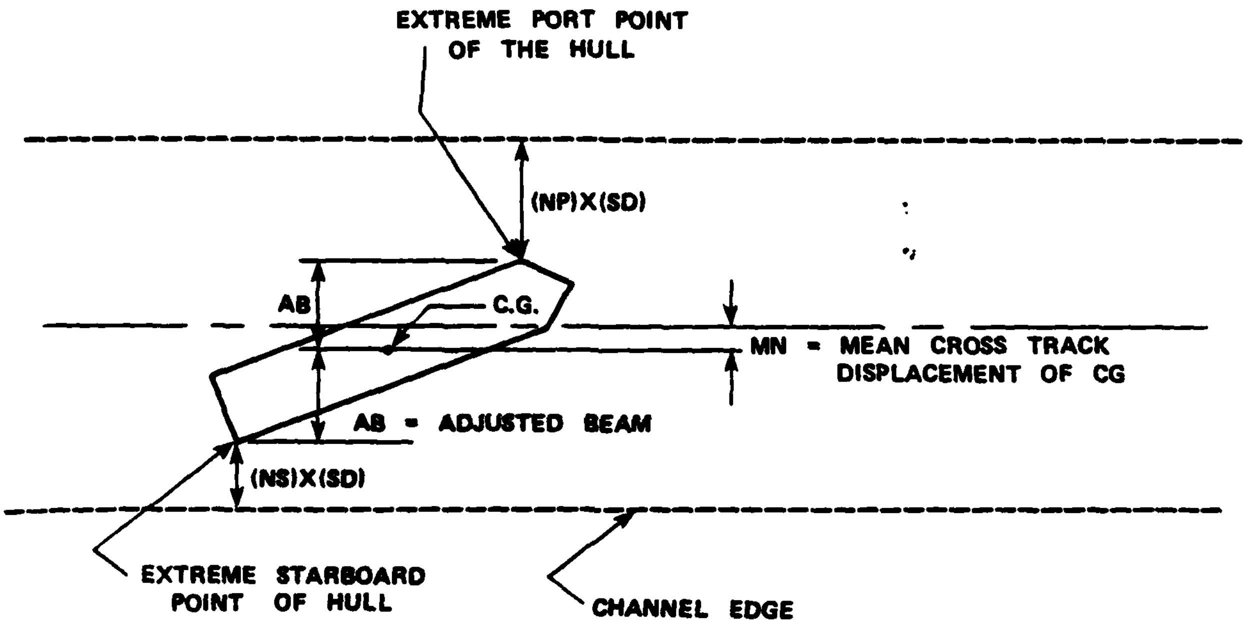
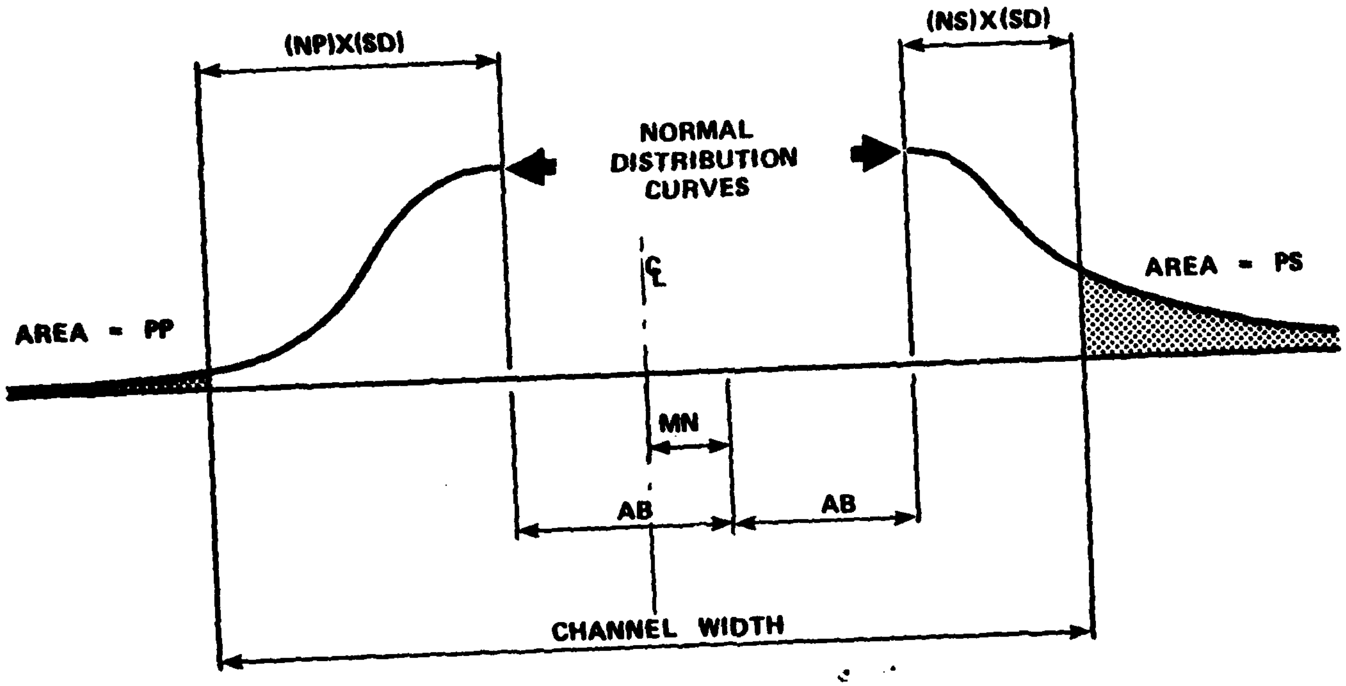


Figure 3-1. Relationship of Mean Crosstrack Position and Standard Deviation to Ship Orientation and Channel Edges



RRF = PP+PS

Figure 3-2. Derivation of Relative Risk Factor
Based on the Assumption of Normal Distribution

The second reason the relative risk factor may be conservative is that most grounding hazards do not exist at the exact edge of the channel. In fact, in many areas a ship may exceed channel edges safely with the grounding hazard being only an occasional shoal. Correction for such phenomenon may be made by using the width of navigable water rather than the channel width for calculating RRF.

A third reason the RRF may be conservative is the beneficial influence of bank effects. Hydrodynamic forces on a ship's hull near a bank will act to repel the ship from the bank with no control input from the pilot. The AN design data do not presently account for this effect.

Although the above considerations prohibit the strict interpretation of the relative risk factor as the probability of gounding, it is seen that in all cases the relative risk factor is a conservative indicator of the probability of grounding. Thus, the RRF contains a built-in safety factor when it is used in a design context. This safety factor is likely beneficial since it allows for a variety of piloting contingencies to be accommodated (e.g., unseasonable tidal currents, piloting errors, passing ship hydrodynamic effects, operation of ships larger than the norm, excessive winds, very limited visibility, unique bottom contours, etc.).

Experience gained through the long term use of the RRF in AN system design will likely identify the proper correction factor to achieve a good estimate of the probability of grounding.

3.3 RISK MANAGEMENT TECHNIQUES IN THE DESIGN OF AN SYSTEMS

The application of risk management techniques to AN system design supports design methods which seek to "manage" the risk of accidents. The design methods suggested compare alternative designs and do not require an absolute measure of risk. The design methods can be implemented using a relative measure of risk such as the relative risk factor. Two risk management design methods are suggested. The first method seeks to design for minimum risk, in which case the designer seeks to minimize the RRF. The second method seeks to design for an acceptable risk in which case the RRF calculated for an actual channel with an acceptable safety record can be used as a goal for the channel under consideration.

3.3.1 Design Method 1: Design for Minimum Risk

A policy decision may be made to design the AN system in a selected waterway to achieve a minimum risk of accident. Such a decision might be made for those waterways which support the transportation of high risk cargos (e.g., liquid natural gas) or for those which support a high frequency of ship transits (e.g., Houston Ship Channel). The minimum risk design method requires identification of the minimum AN configuration which will achieve a minimum relative risk factor. This design method will identify the AN system which provides minimum risk of accident (i.e., maximum safety) without incurring costs of excessive AN markings. While the design for minimum risk provides for the safest

ship operations, it will also likely be the most costly to the Coast Guard. Several options might be considered to reduce the system cost while maintaining a minimum relative risk factor. First, operations of high risk cargo vessels might be limited to only the most favorable environmental conditions, e.g., slack water, daylight, winds less than 20 knots. Second, high risk operations might be limited only to daylight where the use of alternate unlighted buoys would achieve short spacing and lighted aids at night would achieve long spacing for low risk operations. Third, the U.S. Coast Guard might limit the transit speed for user vessels or limit operations to one-way traffic. Fourth, the Coast Guard might urge the Corps of Engineers to modify the waterway design to achieve the desired relative risk factor with fewer aids. The use of these approaches, however, will require close coordination of various Coast Guard district offices and cooperation with the Corps of Engineers.

Below is an outline of the steps required to achieve a minimum risk AN system design.

Procedure: Design for Minimum Risk

Step 1. Determine the dimensions of the turn, recovery and trackkeeping regions to be marked. Follow the procedures given in Appendix A.

Step 2. Determine adequate AN configurations required in each region. Follow the procedures given in Appendix B.

Step 3. Determine the relative risk factor for each region. Follow the procedures given in Appendix C having selected those AN configurations which meet the adequate marking criteria and which exhibit the lowest standard deviations in the tables of means and standard deviations. For instances where the standard deviations are nearly equal, select the configuration which requires the fewest aids to navigation. Provide range light if they reduce the RRF, if they are practical, and if one-way traffic is considered; or if severe weather will disturb the buoy positions.

Step 4. Identify methods to further reduce risk by considering the effect on the RRF of changing the following conditions:

a. Limit operations to daylight only

b. Limit vessel speeds

c. Limit traffic to one-way operations

d. Limit operations to slack tide

e. Recommend dredging turns to form cutoff turns

f. Recommend dredging to widen channel

3.3.2 Design Method 2: Design for Minimum Cost and Acceptable Risk

The safety records of existing waterways support the assumption that AN system designs exist which are less costly than those required to

achieve minimum risk. The AN system for these waterways are designed to achieve an "acceptable" risk of accidents. This design method seeks to identify AN system designs which achieve relative risk factors equivalent to those of existing channels with proven safety records. The relative risk factors of the existing waterway are used as acceptable risk factors and the design objective is to select minimum cost AN configurations which achieve this factor uniformly along the channel. This design method can be used to identify and eliminate redundancies (over design) and weaknesses (inadequate design) in existing waterways.

Below is an outline of the steps required to achieve an acceptable relative risk factor.

Procedure: Design for an Acceptable Risk

Step 1. Determine the dimensions of the turn, recovery, and trackkeeping regions to be marked. Follow the procedures given in Appendix A.

Step 2. Determine the adequate AN configurations required in each region. Follow the procedures given in Appendix B.

Step 3. Select an acceptable relative risk factor. One possible method is by calculating the RRF for an existing channel with an acceptable safety record, following the procedures given in Appendix C.

Step 4. Calculate the relative risk factor for the channel in question assuming the adequate configuration identified in Step 2. Follow the procedures given in Appendix C.

Step 5. Using a trial and error method select configurations which will achieve the RRF approximately equal to or less than the acceptable RRF. In no instance select a design configuration which is less than the adequate configuration identified in Step 2. Attempt to select configurations which achieve the same RRF in all the regions: turn, recovery, and trackkeeping.

3.4 COST/BENEFIT ANALYSIS IN THE DESIGN OF AN SYSTEMS

The discussion that follows is intended as an exploration of methodology that might be developed, rather than as a finished procedure.

Cost/benefit analyses techniques may be applied to the problem of reducing groundings in narrow waterways where there is usually no loss of life nor injury resulting from the accident. The cost/benefit approach may not be appropriate when loss of life is an issue as in the case of collisions in congested waterways. Yet even the cost of preventing loss of life may have to be equated for the purposes of making policy decisions within the context of limited funds. The cost/benefit design approach may be required to achieve equitable distribution of funds and to justify appropriations for improvements.

The cost/benefit design technique conducts a tradeoff between the annual cost of providing the AN system in the waterway versus the annual average cost of accidents in the waterway. Where:

C_{AN}: annual cost of providing AN system

C_{ACC}: annual average cost of accidents

Each of these costs are made up of several factors which must be identified for the waterway in question. The annual cost of providing the AN system contains the initial cost of the aids amortized over the life of the aids plus the annual cost of the maintenance support required for the particular system (buoy tender, spare parts, replacement buoys, office support, etc.)

$$C_{AN} = (\text{capital cost of AN}) + (\text{maintenance cost of AN}) \qquad (3.3)$$

In order to use this analysis, a mechanism would have to be established in the Coast Guard for tabulating these costs and making them available to the district offices for application in cost/benefit analysis.

The annual average cost of accidents is the product of the average cost per accident, the number of transits per year, the relative risk factor, and a weighting factor. The average cost per accident may be taken as the average ship repair cost plus the loss of revenue during repair plus the cost of environmental clean up or repair to the channel plus the loss of revenue to the port if the channel is closed. The annual average cost of accidents, C_{ACC}, can be calculated as follows:

$$C_{ACC} = (C_{AVG})(N_T)(RRF)(W) \qquad (3.4)$$

where:

C_{AVG}: Average cost per accident

N_T: Number of transits of waterway per year

RRF: Relative risk factor

W: Weighting factor

The average cost of an accident is calculated as follows:

$$C_{AVG} = C_{SHIP} + C_{REV} + C_{ENV} + C_{PORT} \qquad (3.5)$$

where:

C_{SHIP}: Average cost for repair of ship

C_{REV}: Average loss of revenue to ship during repair

C_{ENV}: Average cost for cleanup of environment

C_{PORT}: Average loss of port income while channel blocked during accident

Typical cost values for accidents are needed for the purpose of calculated C_{AVG}. It is beyond the scope of the Phase II study to provide these data. Appropriate data are available in various U.S. Coast Guard, MarAd, and Lloyds reports.

Since the relative risk factor is different for each region on each segment of a channel, the annual average cost of accidents is different for each segment as well; and must be calculated separately. It is also the case that since the relative risk factor is a relative measure, the annual average cost of accidents that is dependent on it becomes a relative measure as well.

The weighting factor, W, is utilized to account for the fact that the relative risk factor may be calculated for specific conditions which occur infrequently. This factor indicates the proportion of time these conditions occur. Table 3-1 illustrates possible uses of W. An accurate calculation of C_{ACC} may be made by accounting for operations under all conditions. Since the relative risk factor is a function of the conditions in the channel, it too will vary as conditions change. The value of C_{ACC} is therefore represented by the weighted sum of all anticipated operating conditions where the sum of the weighting factors is equal to one. The required calculations are as follows:

Given "n" operating conditions:

$$
\begin{aligned}
C_{ACC} = {} & (C_{AVG})\ (N_T)\ (RRF_1)\ (W_1) \\
& + (C_{AVG})\ (N_T)\ (RRF_2)\ (W_2) \\
& + (C_{AVG})\ (N_T)\ (RRF_3)\ (W_3) \\
& \quad \vdots \\
& + (C_{AVG})\ (N_T)\ (RRF_n)\ (W_n)
\end{aligned}
\tag{3.6}
$$

where

$$1 = W_1 + W_2 + W_3 + \ldots + W_n \tag{3.7}$$

3.4.1 Design Points in Cost/Benefit Analysis

The design method using cost/benefit analysis seeks a point for design where an increase in the annual AN system cost, ΔC_{AN}, is approximately equal to the decrease in the average annual accident cost, ΔC_{ACC}. Figure 3-3 shows this design point on a plot of C_{AN} versus C_{ACC}.

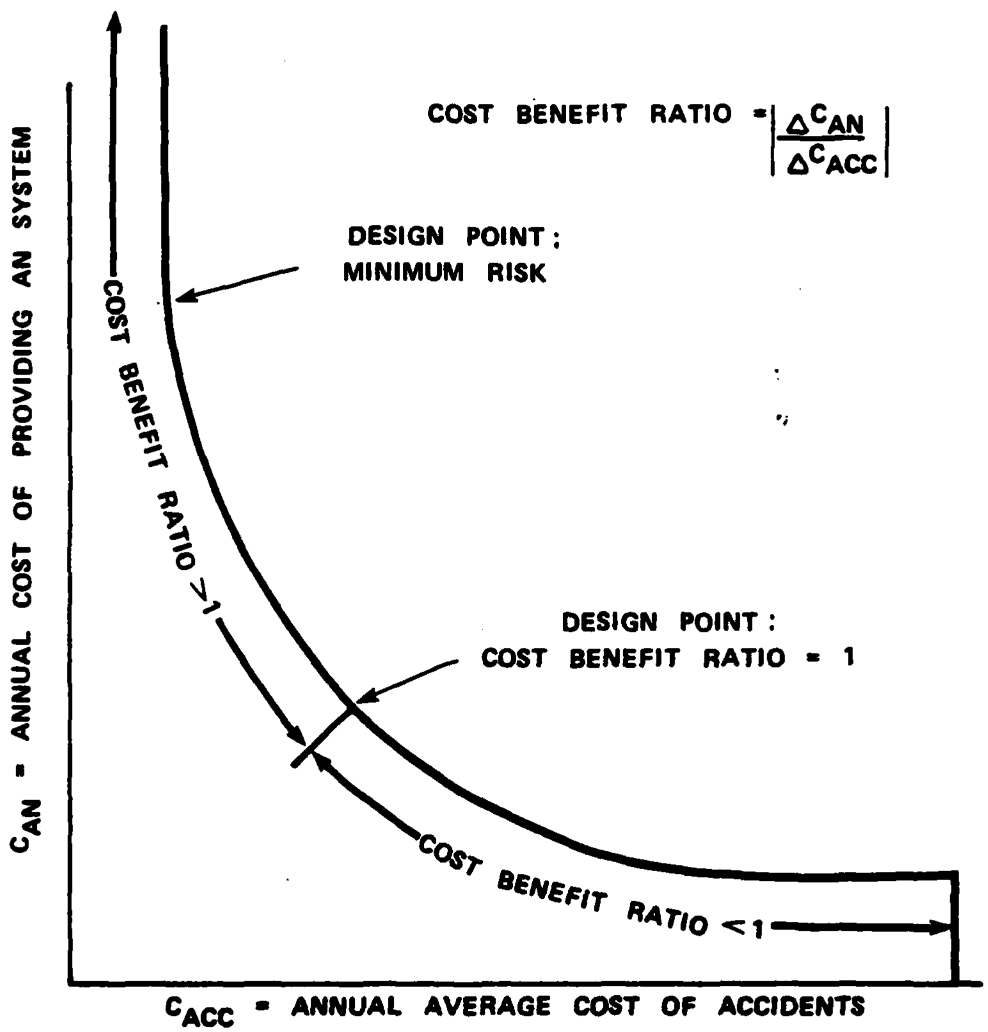


Figure 3-3. Cost Benefit Plot for AN System Designs

TABLE 3-1. POSSIBLE USES FOR WEIGHTING FACTOR, W

Design Conditions	W
Day versus night:	
daylight only	0.50
night only	0.50
	1.00
Severity of conditions:	
slack water or daylight	0.67
maximum flood and ebb current at night	0.33
	1.00
Ship characteristics:	
proportion of traffic identical to design ship	0.XX
proportion of traffic more maneuverable than design ship	0.YY
	1.00

$$\Delta C_{AN} / \Delta C_{ACC} = 1 \quad (3.8)$$

This curve indicates that below the design point the cost/benefit ratio is less than one such that the incremental reduction in accident cost (benefit) is greater than the incremental cost of improving the AN system (cost).

$$\Delta C_{AN} / \Delta C_{ACC} > 1 \quad (3.9)$$

For example: an increase AN system cost of $20,000 per year may contribute to saving $40,000 per year in accident costs. Increases in the cost of the AN system are justified in this region.

Above the design point the cost benefit ratio is greater than one such that the incremental reduction in accident costs (benefit) is less than the incremental cost of improving the AN system (cost).

$$\Delta C_{AN} / \Delta C_{ACC} < 1 \quad (3.10)$$

For example: an increase in AN system of $20,000 may contribute to saving only $10,000 per year in accident costs. Increases in AN system cost in this region is not justifiable from a cost/benefit point of view.

As a matter of practice, analysis of typical ports may show that to reach an acceptable relative risk factor the cost benefit ratio must be greater than one. This may occur particularly in ports where the frequency of transits is low, thus reducing the annual average cost of accidents. There are simply fewer ships which may potentially have an accident, yet sufficient ANs must be provided to achieve an acceptable risk. The cost question for these ports may be between designing for an acceptable relative risk factor versus a minimum relative risk factor.

The design point for a "minimum" relative risk factor occurs where increases in the AN system cost will yield no additional savings in accident costs. This point is shown in Figure 3-3. It may fall either above or below the cost/benefit design point. The point for acceptable relative risk factors may also fall above or below the cost/benefit design point.

Below is an outline of the steps required to conduct a cost/benefit analysis.

Procedure: Design for Cost/Benefit

Step 1. Determine the dimension of the turn, recovery, and trackkeeping regions to be marked. Follow the procedures given in Appendix A.

Step 2. Determine the adequate AN configurations required in each region. Follow the procedures given in Appendix B.

Step 3. Calculate the RRF for the adequate configuration determined in step 2. Calculate C_{AN} and C_{ACC} for this configuration; utilize equations (3.3), (3.4), and (3.5).

Step 4. Determine the AN configuration which achieves a minimum RRF according to the procedures listed in Section 3.3, "Method 1, Design for Minimum Risk." Calculate C_{AN} and C_{ACC} for this configuration; utilize equations (3.3), (3.4), and (3.5).

Step 5. Determine several AN configurations which provide RRFs between those calculated for the adequate AN configuration and the AN configuration for minimum risk. Calculate C_{AN} and C_{ACC} for each configuration.

Step 6. Plot the values of C_{AN} and C_{ACC} for all candidate configurations. C_{AN} as the ordinate (vertical) scale and C_{ACC} as the abscissa (horizontal) scale. Utilize the same scale factor on each axis. Draw a curve between the points.

Step 7. Select the configuration nearest the point on curve where the absolute value of the slope is equal to 1.

If the absolute value of the slope for the entire curve is numerically less than 1.0, select the adequate AN configuration identified in Step 2.

If the absolute value of the slope for the entire curve is numerically greater than 1.0, select the AN configuration which achieves minimum risk as identified in step 4.

3.5 SAMPLE APPLICATION OF THE RRF IN AN SYSTEM DESIGN

The entrance channels to Tampa Bay have been identified as potential problem areas in Section 2.0. Although marked with gated buoys,

typically only one buoy of the pair is a lighted buoy so that the configurations appear as gated during the day and staggered at night. Figure 3-4 shows the existing markings for Mullet Key and Cut A channels. Mullet Key is 500 feet wide while Cut A is 400 feet wide.

The sample analysis of the existing AN configurations in Section 2 indicated that the existing aids may be inadequate. There exists, however, no unique operating requirements for the port to suggest that there is a need to design for minimum risk. Therefore, it seems appropriate to design for acceptable risk as outlined in Section 3.3.

The initial task is that of finding an acceptable RRF. As an example, performance in Mullet Key during the day, with adequate markings as selected in Section 2, will be used to calculate an acceptable RRF. Ideally the safety record of this particular channel would be reviewed to verify this assumption. Further, it will be assumed that identical RRF will be required for both day and night conditions since large ship, commercial operations occur 24 hours a day in this port.

The following AN design parameters are assumed for the port and channels of interest:

Usership:	30,000 dwt tanker
Length:	596 feet
Beam:	84 feet
Minimum transit speed:	6 knots
Maximum transit speed:	12 knots
Maximum crosscurrent:	0 knots
Maximum wind:	20 knots
Traffic:	Two way

RRF calculations can be made for three possible AN conditions: existing buoys (night, staggered buoys only), adequate buoys (gated buoys, long spacing), and existing range lights (high sensitivity ranges). Figures 3-5, 3-6, and 3-7 show these calculations. The baseline mean, baseline standard deviation, and correction factors are selected for the appropriate operating conditions in accordance with the data tables for recovery regions found in Section C.3 of Appendix C. The baseline mean values include the value of one-sixth the channel width to account for two-way traffic. The resultant values for the RRF are summarized in Table 3-2. Similar calculations made for Cut A channel are also shown. The increases in RRF for Cut A reflect the reduction in channel width. Note A indicates that the RRFs calculated for the existing night conditions may be optimistically small since design data are not available for buoy markings as sparse as those shown in the existing channel. The RRFs indicated show the vast improvement provided by the range lights. The RRF in Mullet Key is decreased from 0.2119 to 0.0006 with the inclusion of the range lights. The RRF in Cut A is decreased from 0.3632 to 0.0207 with the addition of range lights. These data indicate the critical dependence of performance in these two channels on range lights alone. They also provide some insight into how severely performance in these channels may be degraded if the range

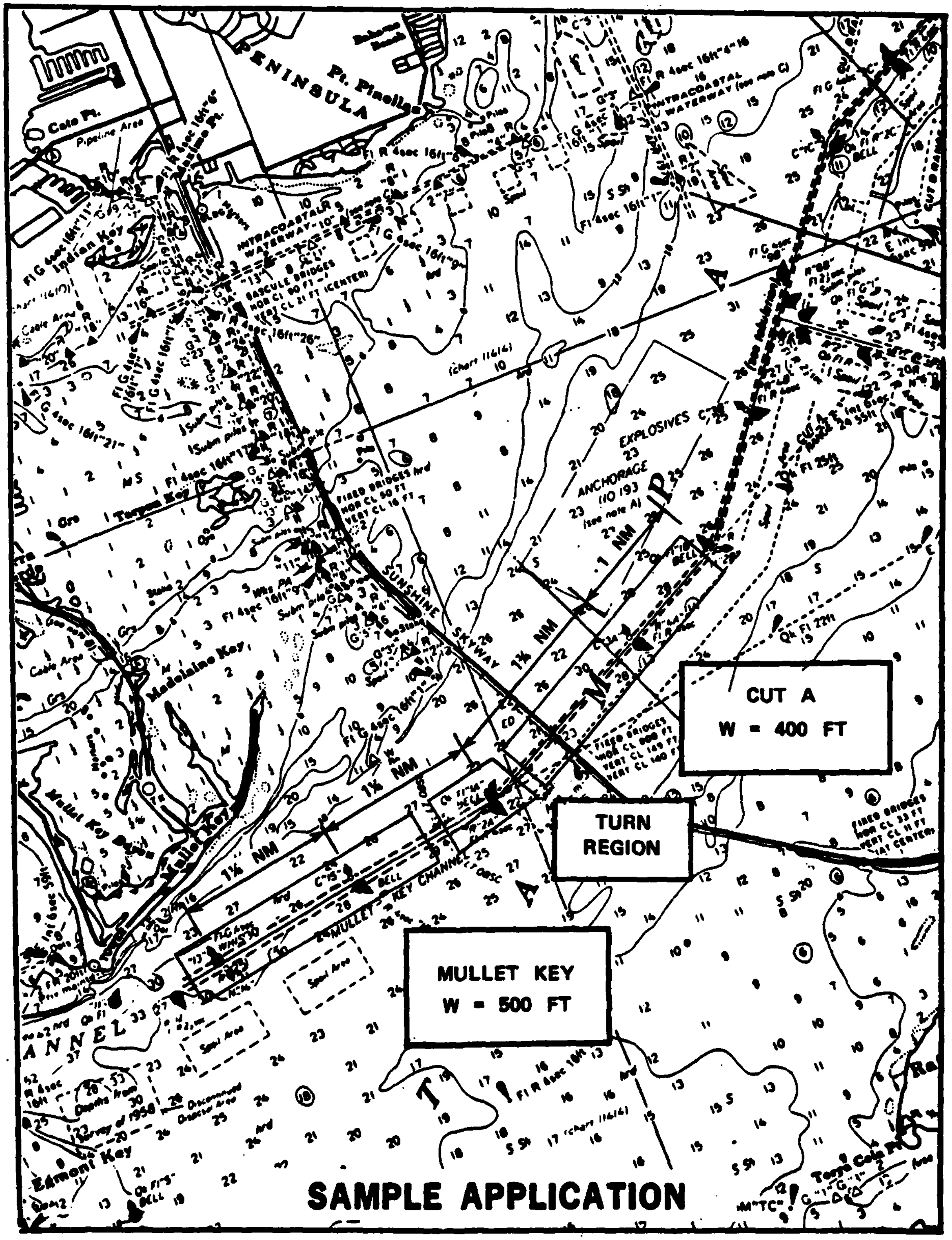


Figure 3-4. Conditions in Mullet Key and A Channels, Tampa Bay
(Chart 11414, March 28, 1981, With Additions)

CALCULATION OF RRF:

FORM YYY

RECOVERY REGION

CHANNEL IDENTIFICATION

1. CHANNEL NAME AND LOCATION: Mullet Key, Tampa Bay	2. CHART NO. 11414
3. LATITUDE AND LONGITUDE OF MID POINT	

CHANNEL AND ENVIRONMENTAL PARAMETERS

4. ENTER CHANNEL WIDTH (FEET)	W= 500 FT
5. ENTER MAXIMUM CROSS CURRENT COMPONENT (KNOTS)'	VX= 0 KTS
6. ENTER MAXIMUM WIND VELOCITY (KNOTS)	VW= 20 KTS

DESIGN VESSEL PARAMETERS

7. ENTER SHIP TYPE AND DWT	TANKER/30K
8. ENTER MINIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMIN= 6 KTS
9. ENTER MAXIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMAX= 12 KTS
10. ENTER SHIPS LENGTH (FEET)	L= 596 FT
11. ENTER SHIPS BEAM (FEET)	B= 84 FT

SRA DESIGN PARAMETERS (CIRCLE ONE)

12. AN DETECTION DISTANCE		LESS THAN AN SPACING (RADAR)	GREATER THAN AN SPACING (VISUAL)
13. DAYLIGHT CONDITIONS		DAY	NIGHT, DUSK OR DAWN
14. AN CONFIGURATION: (IF RADAR):	GATED LO SENS RNG RACON LEADING MARK	STAGGERED	ONE-SIDE HI SENS RNG RACON RANGES
15. AN SPACING	5/8 NM	1 NM	1 1/4 NM
16. TRAFFIC CONDITION		ONE WAY	TWO WAY
17. MAX EXPECTED DRIFT ANGLE	TAN^{-1} (LINE 5 / LINE 8) (0/6) =		DA= 0 DEG

RADIO AID DESIGN PARAMETERS (CIRCLE ONE)

18. GYRO AIDING	YES		NO
19. RMS NOISE AT SITE (METERS)	0 TO 5 M	5 TO 10 M	10 TO 30 M
20. DISPLAY FORMAT	GRAPHIC W/VECTOR PERSPECTIVE	DIGITAL/DISTANCE	GRAPHIC W/PREDICTOR DIGITAL/TURN
21. THROUGH SYSTEM RISE TIME	3 SEC	12 SEC	24 SEC

CALCULATE ADJUSTED MN AND SD

21A ENTER BASELINE MEAN TABLE C.8,C.9,C.10 MN	23A ENTER MEAN SHIP CORRECTION FACTOR TABLE C.11 MCSHP	24A ENTER MEAN SPEED CORRECTION FACTOR TABLE C.12 MCSPD	25A ENTER MEAN WIDTH CORRECTION FACTOR TABLE C.13 MCWID		26 CALCULATE ADJUSTED MEAN MN'
(120 FT) x	(1.0) x	(1.3) x	(1.0)	=	(156 FT)

22B ENTER BASELINE STD. DEV. 1 TABLE C.8,C.9,C.10 SD	23B ENTER S.D. SHIP CORRECTION FACTOR TABLE C.11 SCSHP	24B ENTER S.D. SPEED CORRECTION FACTOR TABLE C.12 SCSPD	25B ENTER S.D. WIDTH CORRECTION FACTOR TABLE C.13 SCWID		27 CALCULATE ADJUSTED STD. DEV. SD'
(65 FT) x	(1.0) x	(1.0) x	(1.0)	=	(65 FT)

CALCULATE ADJUSTED BEAM

28 ENTER SHIP LENGTH LINE 10 L	29 ENTER CROSS TRACK CURRENT VELOCITY LINE 5 VX	30 ENTER MINIMUM EXPECTED SPEED LINE 8 VMIN		31 ENTER SHIPS BEAM LINE 11 B		32 CALCULATE ADJUSTED BEAM B'
(596 /2) x	(0 /	6)	+	(84 /2)	=	(42 FT)

CALCULATE THE RELATIVE RISK FACTOR

33A ENTER CHAN. WIDTH LINE 4 W	34A ENTER ADJUSTED MEAN LINE 26 MN'	35A ENTER ADJUSTED BEAM LINE 32 B'		36A ENTER ADJUSTED STD. DEV. LINE 27 SD'		37 CALCULATE S.D. MULTIPLE TO STARBOARD NS
(500 /2) -	(156) -	(42)	/	(65)	=	(.80)

33B ENTER CHAN. WIDTH LINE 4 W	34B ENTER ADJUSTED MEAN LINE 26 MN'	35B ENTER CHAN. ADJUSTED BEAM LINE 32 B'		36B ENTER ADJUSTED STD. DEV. LINE 27 SD'		38 CALCULATE S.D. MULTIPLE TO PORT NP
(500 /2) +	(156) -	(42)	/	(65)	=	(5.60)

39 DETERMINE PROB. OF CROSSING NS TABLE C.1 PS	40 DETERMINE PROB. OF CROSSING NP TABLE C.1 PP		41 CALCULATE RELATIVE RISK FACTOR RRF
(.2119) +	(.0000)	=	(.2119)

Figure 3-5. Sample Calculation of RRF for Mullet Key, Staggered Buoys, Long Spacing

FORM YYY

CALCULATION OF RRF: RECOVERY REGION

CHANNEL IDENTIFICATION

1. CHANNEL NAME AND LOCATION: MULLET KEY, TAMPA BAY	2. CHART NO. 11414
3. LATITUDE AND LONGITUDE OF MID POINT	

CHANNEL AND ENVIRONMENTAL PARAMETERS

4. ENTER CHANNEL WIDTH (FEET)	W= 500 FT
5. ENTER MAXIMUM CROSS CURRENT COMPONENT (KNOTS)	VX= 0 KTS
6. ENTER MAXIMUM WIND VELOCITY (KNOTS)	VW= 20 KTS

DESIGN VESSEL PARAMETERS

7. ENTER SHIP TYPE AND DWT	TANKER/30K
8. ENTER MINIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMIN= 6 KTS
9. ENTER MAXIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMAX= 12 KTS
10. ENTER SHIPS LENGTH (FEET)	L= 596 FT
11. ENTER SHIPS BEAM (FEET)	B= 84 FT

SRA DESIGN PARAMETERS: (CIRCLE ONE)

12. AN DETECTION DISTANCE	LESS THAN AN SPACING (RADAR)	GREATER THAN AN SPACING (VISUAL)	
13. DAYLIGHT CONDITIONS	DAY	NIGHT, DUSK OR DAWN	
14. AN CONFIGURATION: (IF RADAR):	GATED LO SENS RNG RACON LEADING MARK	STAGGERED HI SENS RNG RACON RANGES	ONE-SIDE
15. AN SPACING	5/8 NM	1 NM	1 1/4 NM
16. TRAFFIC CONDITION	ONE WAY	TWO WAY	
17. MAX EXPECTED DRIFT ANGLE	TAN^{-1} (LINE 5 / LINE 8) (0/6) =	DA= 0 DEG	

RADIO AID DESIGN PARAMETERS (CIRCLE ONE)

18. GYRO AIDING	YES	NO	
19. RMS NOISE AT SITE (METERS)	0 TO 6 M	6 TO 18 M	18 TO 36 M
20. DISPLAY FORMAT	GRAPHIC W/VECTOR PERSPECTIVE	DIGITAL/DISTANCE	GRAPHIC W/PREDICTOR DIGITAL/TURN
21. THROUGH SYSTEM RISE TIME	3 SEC	12 SEC	24 SEC

CALCULATE ADJUSTED MN AND SD

21A ENTER BASELINE MEAN TABLE C.8,C.9,C.10 MN	22A ENTER MEAN SHIP CORRECTION FACTOR TABLE C.11 MCSHP	24A ENTER MEAN SPEED CORRECTION FACTOR TABLE C.12 MCSPD	25A ENTER MEAN WIDTH CORRECTION FACTOR TABLE C.13 MCWID		26 CALCULATE ADJUSTED MEAN MN'
(87 FT) x	(1.0) x	(1.3) x	(1.0)	=	(113 FT)

22B ENTER BASELINE STD. DEV. 1 TABLE C.8,C.9,C.10 SD	23B ENTER S.D. SHIP CORRECTION FACTOR TABLE C.11 SCSHP	24B ENTER S.D. SPEED CORRECTION FACTOR TABLE C.12 SCSPD	25B ENTER S.D. WIDTH CORRECTION FACTOR TABLE C.13 SCWID		27 CALCULATE ADJUSTED STD. DEV. SD'
(40 FT) x	(1.0) x	(1.0) x	(1.0)	=	(40 FT)

CALCULATE ADJUSTED BEAM

28 ENTER SHIP LENGTH LINE 10 L	29 ENTER CROSS TRACK CURRENT VELOCITY LINE 5 VX	30 ENTER MINIMUM EXPECTED SPEED LINE 8 VMIN		31 ENTER SHIPS BEAM LINE 11 B		32 CALCULATE ADJUSTED BEAM B'
(596 /2) x	(0 /	6)	+	(84 /2)	=	(42 FT)

CALCULATE THE RELATIVE RISK FACTOR

33A ENTER CHAN. WIDTH LINE 4 W	34A ENTER ADJUSTED MEAN LINE 26 MN'	35A ENTER ADJUSTED BEAM LINE 32 B'		36A ENTER ADJUSTED STD. DEV. LINE 27 SD'		37 CALCULATE S.D. MULTIPLE TO STARBOARD NS
(500 /2) -	(113) -	(42)	/	(40)	=	(2.38)

33B ENTER CHAN. WIDTH LINE 4 W	34B ENTER ADJUSTED MEAN LINE 26 MN'	35B ENTER CHAN. ADJUSTED BEAM LINE 32 B'		36B ENTER ADJUSTED STD. DEV. LINE 27 SD'		38 CALCULATE S.D. MULTIPLE TO PORT NP
(500 /2) +	(113) -	(42)	/	(40)	=	(8.03)

39 DETERMINE PROB. OF CROSSING NS TABLE C.1 PS	40 DETERMINE PROB. OF CROSSING NP TABLE C.1 PP		41 CALCULATE RELATIVE RISK FACTOR RRF
(.0087) +	(.0000)	=	(.0087)

Figure 3-6. Sample Calculation of RRF for Mullet Key, Gated Buoys, Long Spacing

FORM .YYY

CALCULATION OF RRF: RECOVERY REGION

CHANNEL IDENTIFICATION

1. CHANNEL NAME AND LOCATION Mullet Key, Tampa Bay	2. CHART NO. 11414
3. LATITUDE AND LONGITUDE OF MID POINT	

CHANNEL AND ENVIRONMENTAL PARAMETERS

4. ENTER CHANNEL WIDTH (FEET)	W= 500 FT
5. ENTER MAXIMUM CROSS CURRENT COMPONENT (KNOTS)	VX= 0 KTS
6. ENTER MAXIMUM WIND VELOCITY (KNOTS)	VW= 20 KTS

DESIGN VESSEL PARAMETERS

7. ENTER SHIP TYPE AND DWT	TANKER/30K
8. ENTER MINIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMIN= 6 KTS
9. ENTER MAXIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMAX= 12 KTS
10. ENTER SHIPS LENGTH (FEET)	L= 596 FT
11. ENTER SHIPS BEAM (FEET)	B= 84 FT

SRA DESIGN PARAMETERS (CIRCLE ONE)

12. AN DETECTION DISTANCE	LESS THAN AN SPACING (RADAR)	GREATER THAN AN SPACING (VISUAL)	
13. DAYLIGHT CONDITIONS	DAY	NIGHT, DUSK OR DAWN	
14. AN CONFIGURATION: (IF RADAR):	GATED LO SENS RNG RACON LEADING MARK	STAGGERED HI SENS RNG RACON RANGES	ONE-SIDE
15. AN SPACING	5/8 NM	1 NM	1 1/4 NM
16. TRAFFIC CONDITION	ONE WAY	TWO WAY	
17. MAX EXPECTED DRIFT ANGLE	$\tan^{-1}$ (LINE 5 / LINE 8) (0/6) =	DA= 0 DEG	

18. GYRO AIDING	YES	NO	
19. RMS NOISE AT SITE (METERS)	0 TO 6 M	6 TO 18 M	18 TO 30 M
20. DISPLAY FORMAT	GRAPHIC W/VECTOR PERSPECTIVE	GRAPHIC W/PREDICTOR DIGITAL/DISTANCE	DIGITAL/TURN
21. THROUGH SYSTEM RISE TIME	3 SEC	12 SEC	24 SEC

CALCULATE ADJUSTED MN AND SD

21A ENTER BASELINE MEAN TABLE C.8,C.9,C.10 MN	22A ENTER MEAN SHIP CORRECTION FACTOR TABLE C.11 MCSHP	24A ENTER MEAN SPEED CORRECTION FACTOR TABLE C.12 MCSPO	25A ENTER MEAN WIDTH CORRECTION FACTOR TABLE C.13 MCWID		26 CALCULATE ADJUSTED MEAN MN'
(98 FT) ×	(1.0) ×	(1.3) ×	(1.0)	=	(127 FT)

21B ENTER BASELINE STD. DEV. 1 TABLE C.8,C.9,C.10 SD	22B ENTER S.D. SHIP CORRECTION FACTOR TABLE C.11 SCSHP	24B ENTER S.D. SPEED CORRECTION FACTOR TABLE C.12 SCSPD	25B ENTER S.D. WIDTH CORRECTION FACTOR TABLE C.13 SCWID		27 CALCULATE ADJUSTED STD. DEV. SD'
(25 FT) ×	(1.0) ×	(1.0) ×	(1.0)	=	(25 FT)

CALCULATE ADJUSTED BEAM

28 ENTER SHIP LENGTH LINE 10 L	29 ENTER CROSS TRACK CURRENT VELOCITY LINE 5 VX	30 ENTER MINIMUM EXPECTED SPEED LINE 8 VMIN		31 ENTER SHIPS BEAM LINE 11 B		32 CALCULATE ADJUSTED BEAM B'
(596 /2) ×	(0 /	6)	+	(84 /2)	=	(42 FT)

CALCULATE THE RELATIVE RISK FACTOR

33A ENTER CHAN. WIDTH LINE 4 W	34A ENTER ADJUSTED MEAN LINE 26 MN'	35A ENTER ADJUSTED BEAM LINE 32 B'		36A ENTER ADJUSTED STD. DEV. LINE 27 SD'		37 CALCULATE S.D. MULTIPLE TO STARBOARD NS
(500 /2) −	(127) −	(42)	/	(25)	=	(3.24)

33B ENTER CHAN. WIDTH LINE 4 W	34B ENTER ADJUSTED MEAN LINE 26 MN'	35B ENTER CHAN. ADJUSTED BEAM LINE 32 B'		36B ENTER ADJUSTED STD. DEV. LINE 27 SD'		38 CALCULATE S.D. MULTIPLE TO PORT NP
(500 /2) +	(127) −	(42)	/	(25)	=	(13.40)

39 DETERMINE PROB. OF CROSSING NS TABLE C.1 PS	40 DETERMINE PROB. OF CROSSING NP TABLE C.1 PP		41 CALCULATE RELATIVE RISK FACTOR RRF
(.0006) +	(.0000)	=	(.0006)

Figure 3-7. Sample Calculation of RRF for Mullet Key, High Sensitivity Range Lights

TABLE 3-2. RRF FOR TAMPA BAY ENTRANCE CHANNELS, TWO-WAY TRAFFIC

AN Configuration:	Mullet Key	Cut A
Existing Buoys (night)	0.2119 (Note A)	0.3632 (Note A)
Adequate buoys	0.0087	0.0571
Existing range lights	0.0006 (Note B)	0.0207 (Note B)

NOTE A: The RRFs indicated are likely optimisticially low because spacing in the actual channel is 2-1/2 nm according to the definition of spacing for staggered buoys adopted for this manual (see instruction 14, Section C.3 of Appendix C). This spacing far exceeds the limits of the tables for baseline means and standard deviations shown for spacing up to 1-1/4 nm.

NOTE B: High sensitivity ranges exist in both Mullet Key and Cut A channels: Mullet Key, $K = 3.4$ to 7.3; Cut A, $K = 4.0$ to 19.0.

TABLE 3-3. RRF FOR TAMPA BAY ENTRANCE CHANNELS, ONE-WAY TRAFFIC

AN Configurations:	Mullet Key	Cut A
Existing buoys (night)	0.0069	0.0463
Adequate buoys	0.0000	0.0001
Existing range lights	0.0000	0.0000

lights are obscured from visibility by rain, fog, mist, etc., or confused with background and/or traffic ship lights. Notice also that when outbound, both ranges lie astern of ownship.

The RRFs calculated for the "adequate" AN configuration shown in Figure 3-8 illustrate that the addition of two buoy gates, the lighting of three unlighted buoys, and the adequate marking of the turn will signficantly improve piloting performance when the range lights cannot be utilzed. The addition of buoys in Mullet Key will lower the RRF from 0.2119 to 0.0087. The addition of buoys in Cut A will lower the RRF from 0.3632 to 0.0571.

It is of interest as a comparative analysis to calculate the RRFs for one-way traffic in these channels. The above calculation for two-way traffic required the adjustment of the means from the centerline by 1/6 of the width of the channel for traffic, an adjustment which results in larger RRFs. If one-way traffic is assumed and this adjustment is not made, the resulting RRFs are correspondingly smaller. The consideration of these smaller RRFs requires the assumption that one-way traffic is the predominant operation of the port with two-way traffic existing for only the relatively short period of time it takes two ships to pass each other. Table 3-3 summarizes the RRFs calculated for one-way operation for identical conditions as those for Table 3-2. A marked decrease in RRFs is achieved by assuming the ships are transiting near the channel centerline. Comparison of data in Tables 3-2 and 3-3 allows the designer to assess the impact of providing adequate markings as suggested in Figure 3-8. Adequate markings support two-way traffic operations at a performance level at least as good as that for one-way operations with existing AN configurations (excluding the use of range lights).

The final decision as to whether or not to add buoys to Mullet Key or Cut A channels will require the selection of a maximum value for the RRF. Once such a value is selected, the designer need only evaluate configurations which achieve a value less than the maximum. Such a maximum value might be derived by analyzing the RRFs for a number of existing channels which are adequately marked and which exhibit acceptable safety records. Consideration of how to trade off RRFs between range lights and buoys, however, must also be considered. Certainly, range lights can be relied upon more heavily in ports with seasonable good visibility. Where visibility is more variable, however, the buoys must provide adequate guidance. Finally, cost/benefit analyses must be considered. In the example given, the number of buoys in Mullet Key and Cut A Channels was almost doubled, a significant increase. On the other hand, the RRF; the risk of accidents; and, by extension, their cost was reduced substantially. Equating these costs and savings to actual dollars should provide ample justification for the appropriations necessary to make the suggested changes.

One final observation may be made from these data. The RRFs calculated for Mullet Key and Cut A indicate that piloting performance in the present channels is critically dependent on the operation of the range lights. These particular range lights should be assigned a high

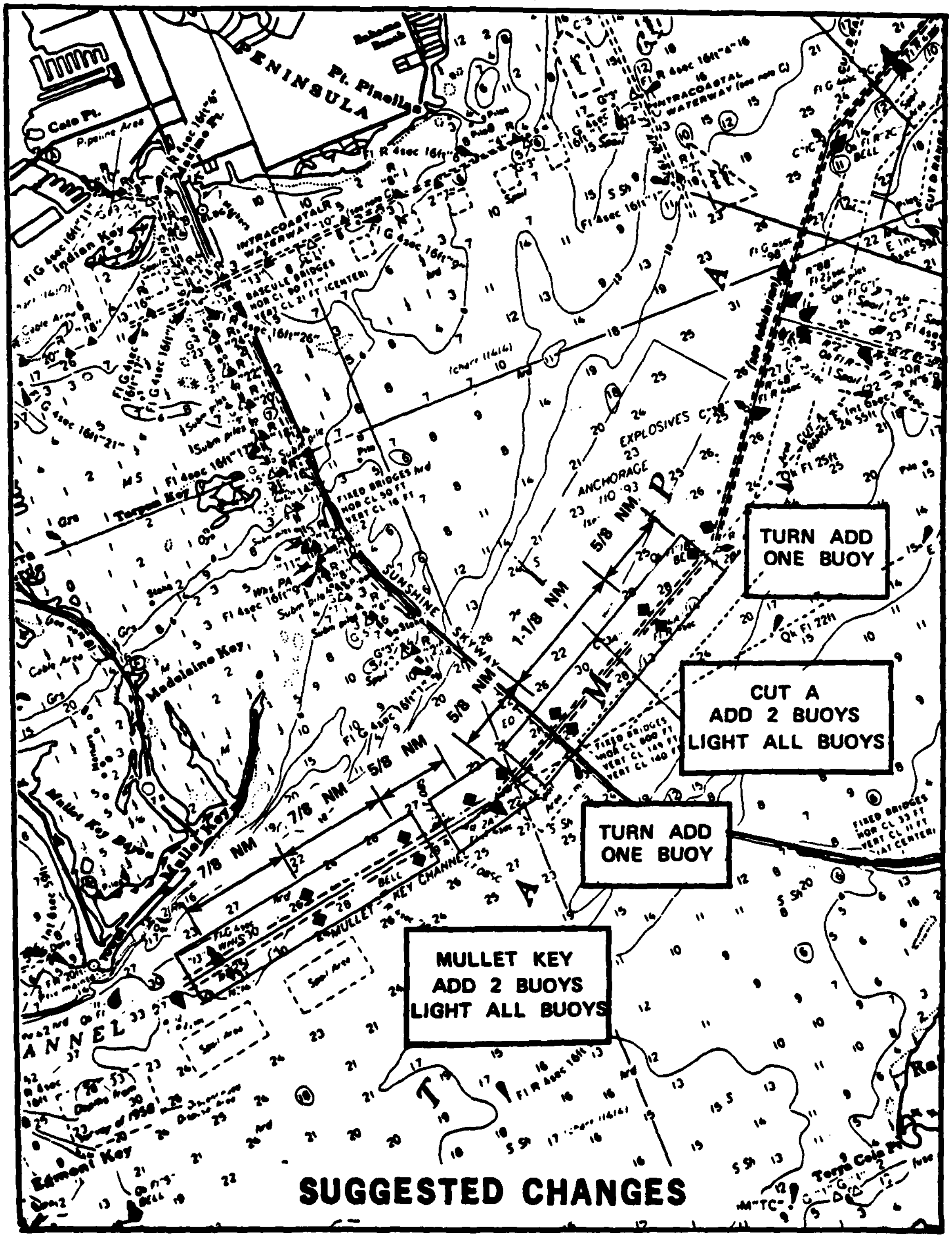


Figure 3-8. Recommended Buoy Configurations for Mullet Key and Cut A Channels, Tampa Bay (Chart 11414, March 28, 1981, With Additions)

maintenance priority in accordance with the discussion of Section 1. Thus, the RRFs of different AN systems operating in the same channels (radio aid, SRA, radar piloting) can also be useful in resolving questions in establishing maintenance priorities.

APPENDIX A

DETERMINE NAVIGATION REGION

The severity of maneuvering necessary in each region of the channel determines the need for aid number and placement. The division of the channel into three regions allows for different requirements to be applied in each region. The regions illustrated in Figure A-1 are as follows:

1. The turn region encloses the severest maneuver, with the necessity that the pilot make rapid, frequent judgements of the ship's alongtrack and acrosstrack positions and velocities. For this reason, the turn has the strictest requirements for aid number and placement.

2. The recovery region encloses the pilot's efforts to find the appropriate track in the new channel leg and maneuver the ship to it. To do this, the pilot needs precise knowledge of the edges of the channel and of the ship's relationship to them. The region must be well marked for this. The aid requirements for changing track -- in response to current, traffic, etc. -- are similar to those for finding a track after a turn.

3. The trackkeeping region encloses the channel segment in which the pilot is satisfied with the ship's track in the channel and has no intention or need to leave that track. For this reason he does not need precise knowledge of the channel edges. He needs only enough aids to give him a short-range destination up ahead.

The purpose of this section is to provide instructions for the division of the subject channel into regions. The division is not arbitrary, but depends on the physical channel dimensions, the environmental conditions, the ships that use the channel, and operational requirements.[1]

To begin, the subject channel should be marked off roughly into regions as illustrated in Figure A-1. First, each turn should be marked off as a region. Second, there should be a recovery region adjacent to each turn region in both directions. Lastly, the middle portion of each straight channel segment should be marked as a potential trackkeeping region. Each indicated region is a subject for application of the processes described in this manual. The procedures in this appendix assign more precise distances to these regions.

Step 1: The user should begin by determining the distance of each turn region in the channel as instructed in Section A.1.

Step 2: The distance of each recovery region should be determined as instructed in Section A.2.

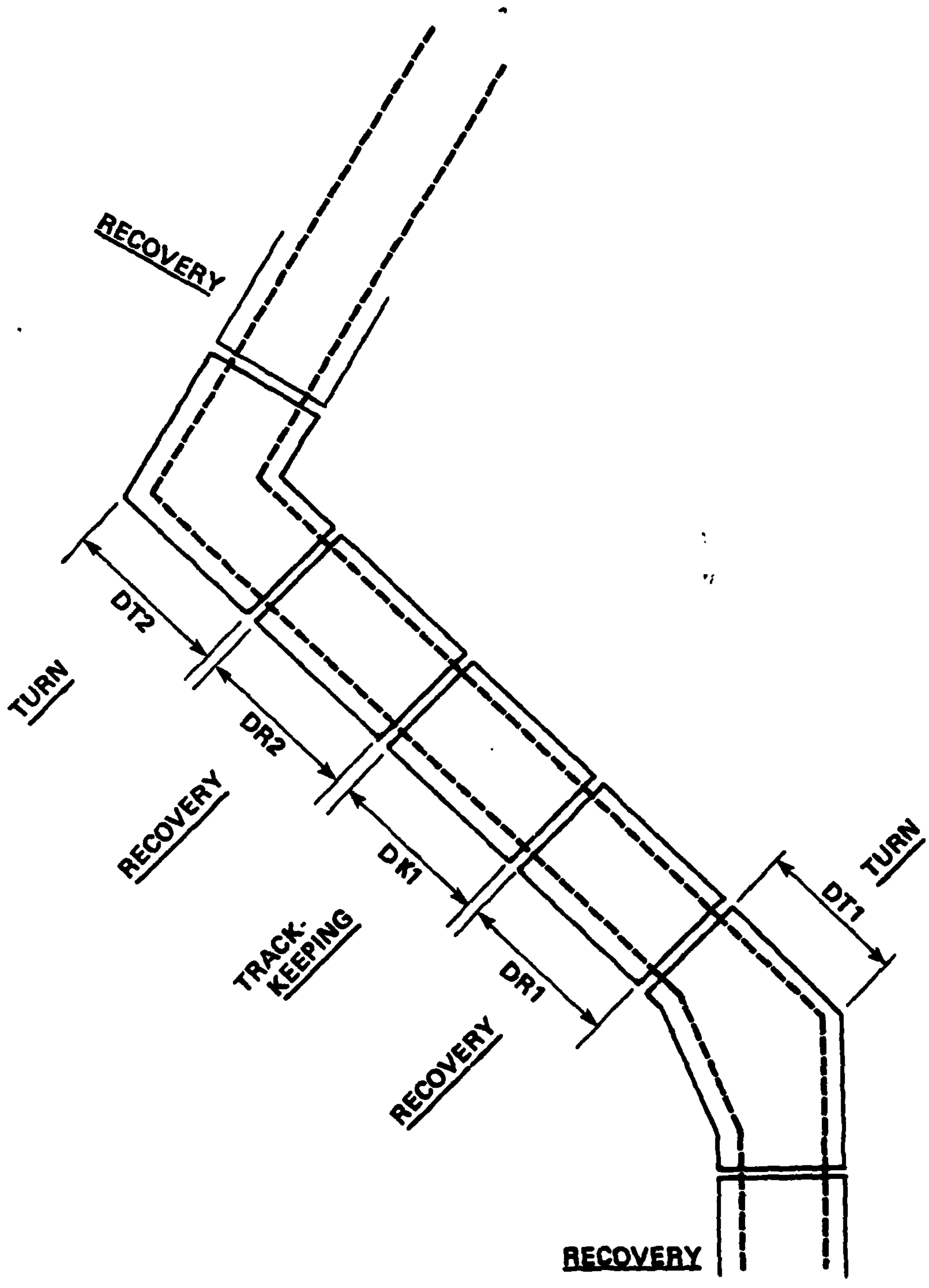


Figure A-1. Determine Navigation Regions

Step 3: The distance of each remaining trackkeeping region should be determined according to Section A.3.

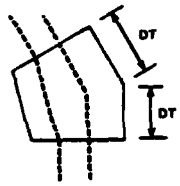
The procedures presented here instruct the user to report conditions in the subject channel. More information is requested than is necessary for the determination of the regions. The additional information is preparation for determining adequate AN marking and relative risk factor in Appendices B and C.

A.1 DETERMINE THE DISTANCE (DT) OF EACH TURN REGION

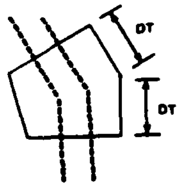
This section includes Form NNN that appears as Figure A-2 on which the user will report conditions for the individual turn. There are instructions for filling in each line of the form. The numbered instructions correspond to the identical numbered boxes on the form. Table A-1 lists the rules relating the reported conditions to the determined distance, DT. The distance may be recorded on Form NNN. Figure A-2 also shows a variety of alternative buoy arrangements that are discussed in Appendix B.

TABLE A-1. RULES DETERMINING THE DISTANCE (DT) OF EACH TURN REGION

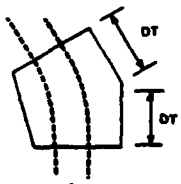
Rule 1: For a cutoff turn DT is from one end of the cutoff to the [2]



Rule 2: For a noncutoff turn DT is 0.50 nm in each direction from the apex of the turn.[3]



Rule 3: Bends should be treated as a cutoff.[4]



Rule 4: A channel entrance from the open sea should be treated as a recovery region.[5]

Instructions

1. Enter a written description of the turn and the waterway or port name.

FORM NNN

TURN REGION IDENTIFICATION

1. TURN NAME AND LOCATION	2. CHART NO.
3. LATITUDE AND LONGITUDE OF TURN APEX	

CHANNEL AND ENVIRONMENTAL PARAMETERS

4. ENTER CHANNEL WIDTH (FEET)	W= FT
5. ENTER MAXIMUM CROSS CURRENT COMPONENT (KNOTS)	VX= KTS
6. ENTER MAXIMUM WIND VELOCITY (KNOTS)	VW= KTS

DESIGN VESSEL PARAMETERS

7. ENTER SHIP TYPE AND DWT	
8. ENTER MINIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMIN= KTS
9. ENTER MAXIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMAX= KTS
10. ENTER SHIPS LENGTH (FEET)	L= FT
11. ENTER SHIPS BEAM (FEET)	B= FT

SRA DESIGN PARAMETERS (CIRCLE ONE)

12. AN DETECTION DISTANCE	LESS THAN 1 NM (RADAR)	GREATER THAN 1 NM (VISUAL)
13. DAYLIGHT CONDITIONS	DAY	NIGHT, DUSK OR DAWN
14. TURN CONFIGURATIONS	NONCUTOFF	CUTOFF
15. TURN ANGLE	0 TO 20 DEG	20 TO 40 DEG
	GREATER THAN 40 DEG	
16. TRAFFIC	ONE WAY	TWO WAY

DT = 17 ( ) DETERMINE FROM TABLE A1

ADEQUATE NUMBER OF TURN MARKINGS (CIRCLE ONE)

SRA CONFIGURATION	4 BUOYS	3 BUOYS	2 BUOYS	1 BUOY

ADEQUATE PLACEMENT OF TURN MARKINGS

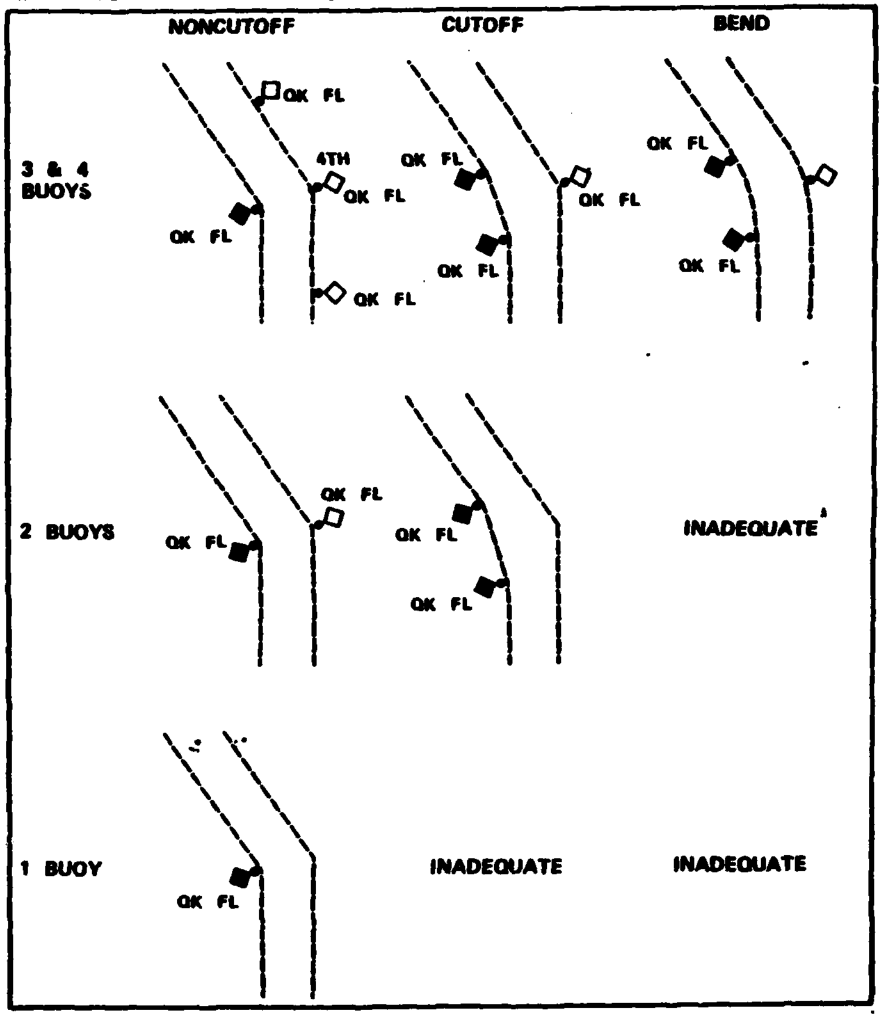


Figure A-2. Determine Distance (DT) of Turn Region: Form NNN

2. Enter the NOAA chart number which provides a detailed diagram of the existing AN configuration and present bathometry (depth) and dimensions.

3. Enter the latitude and longitude of the turn apex midway between the channel edges.

4. Enter the channel width (feet) as indicated on the chart (or) the width of navigable water with regard to the maximum draft of the user vessels.

5. Enter the maximum current component which flows perpendicular to the channel edges on either side of the turn. Enter as a positive value regardless of direction. If none expected, enter 0.5 knots to account for ship lateral drift during the turning maneuver.

6. Enter the maximum wind velocity (knots) which may occur during normal operations. Enter as a positive value regardless of direction.

7. Enter the ship type and deadweight tonnage of the least maneuverable vessel expected to utilize the waterway. This will normally be the ship with the largest dwt. Tug and tow and push barges are not presently considered for design purposes.

8. Enter the minimum expected transit speed for the vessel noted in line 7. If unknown, enter 4.0 knots as a worse case value.

9. Enter the maximum expected transit speed for the vessel noted in line 7. This will typically be the vessel's full ahead maneuvering speed, not its full capability sea speed.

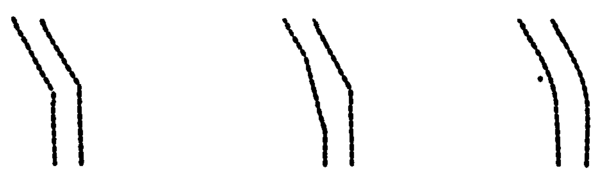
10. Enter the length (feet) of the vessel noted in line 7.

11. Enter the beam (feet) of the vessel noted in line 7.

12. Circle the AN detection distance for which adequacy is to be determined. The AN detection distance is taken to be the distance at which 50 percent of the pilots will see the AN. Radio piloting techniques are assumed for detection distances less than 1 nm. Visual piloting techniques are assumed for detection distances greater than 1 nm.

13. Circle the daylight conditions for which adequacy is to be determined. Night, dusk, and dawn are conservatively assumed to be the same condition.

14. Circle the turn configuration according to the dredged configuration. Bends are assumed to be equivalent to noncutoff turns.



Noncutoff Cutoff Bend

15. Circle the appropriate range for the turn angle. Large angle bends may be assumed to represent a series of cutoff turns as divided by the AN on the inside of the turn.

16. Circle the appropriate traffic condition.

17. Determine the distance, DT, of the turn region from Table A-1 and record.

A.2 DETERMINE THE DISTANCE (DR) OF EACH RECOVERY REGION

This section includes Form 000 that appears as Figure A-3 on which the user will report conditions for each individual recovery region. There are instructions for filling in each line of the form. The numbered instructions correspond to the identical numbered boxes on the form. Table A-2 lists rules relating the reported conditions to the necessary distance. The distance may be recorded on Form 000. Figure A-3 also shows a variety of alternative buoy arrangements that are discussed in Appendix B.

TABLE A-2. RULES DETERMINING THE DISTANCE (DR) OF EACH RECOVERY REGION[6]

Rule 1: For ships up to 30,000 dwt from the turn region in both directions:	DR = 0.70 nm
For ships larger than 30,000 dwt:	add 0.80 nm.[7]
Rule 2: For ships larger than 30,000 dwt with V_{max} greater than 6 knots:	DR is turn to turn.[8]
Rule 3: For crosscurrents requiring 2 to 5 degrees drift angle:	DR is distance affected by current.[9]
Rule 4: For traffic requiring the ship to change tracks:	DR is turn to turn.[10]

Instructions

1. Enter a written description of the channel and the waterway or port name.

2. Enter the NOAA chart number which provides a detailed diagram of the existing AN configuration and present bathometry (depth) and dimensions.

3. Enter the latitude and longitude of a point midway along the channel section and which is midway between the channel edges. (This may be done after the distance of the region has been determined.)

4. Enter the channel width (feet) as indicated on the chart (or) the width of navigable water with regard to the maximum draft of the user vessels.

5. Enter the maximum current component which flows perpendicular to the channel edges. Enter as a positive value regardless of direction. If none expected, enter 0.0.

RECOVERY REGION IDENTIFICATION FORM 000

1. TURN NAME AND LOCATION	2. CHART NO.
3. LATITUDE AND LONGITUDE OF REGION MIDPOINT	

CHANNEL AND ENVIRONMENTAL PARAMETERS

4. ENTER CHANNEL WIDTH (FEET)	W= FT
5. ENTER MAXIMUM CROSS CURRENT COMPONENT (KNOTS)	VX= KTS
6. ENTER MAXIMUM WIND VELOCITY (KNOTS)	VW= KTS

DESIGN VESSEL PARAMETERS

7. ENTER SHIP TYPE AND DWT	
8. ENTER MINIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMIN= KTS
9. ENTER MAXIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMAX= KTS
10. ENTER SHIPS LENGTH (FEET)	L= FT
11. ENTER SHIPS BEAM (FEET)	B= FT

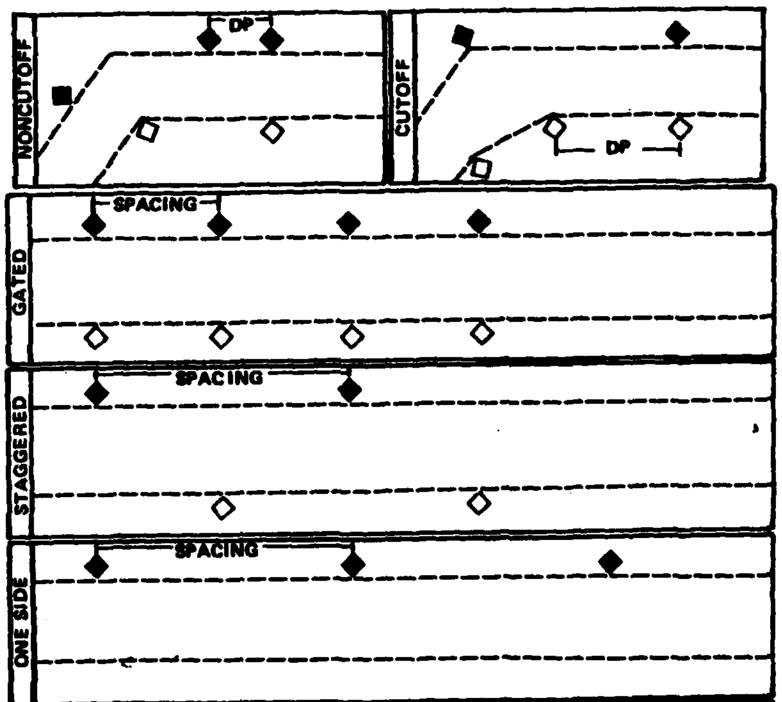
SRA DESIGN PARAMETERS (CIRCLE ONE)

12. AN DETECTION DISTANCE	LESS THAN AN SPACING (RADAR)	GREATER THAN AN SPACING (VISUAL)
13. DAYLIGHT CONDITIONS	DAY	NIGHT, DUSK OR DAWN
14. TRAFFIC	ONE WAY	TWO WAY
15. MAX EXPECTED DRIFT ANGLE $TAN^{-1}(LINE\ 5 / LINE\ 8)$ =	DA = DEG	

DR = | DETERMINE FROM TABLE A.2 16 ( ) |

RECOVERY REGION ADEQUATE CHANNEL MARKING (CIRCLE ONE)

MAXIMUM DISTANCE FROM TURN PULLOUT OR CUTOFF BUOY TO FIRST BUOY	D.P≤3/8 NM	D≤5/8 NM
SRA CONFIGURATION	GATED / STAGGERED HIGH SENS. RANGE	ONE SIDE LOW SENS. RANGE
AN SPACING	SHORT 5/8 TO 7/8 NM	LONG 7/8 TO 1 1/4 NM



RANGES	HIGH SENSITIVITY	LOW SENSITIVITY
	3.0<K<10.0*	0.5<K<1.0
	2<Xa<6 FT*	25<Xa<40 FT

*SEE COAST GUARD PUBLICATION 3?? FOR CALCULATION OF THE VALUES OF LATERAL SENSITIVITY K AND CROSSTRACK POSITION X FOR THE Θ_a DISPLACEMENT (i.e., X_a).

Figure A-3. Determine Distance (DR) of Recovery Region: Form 000

6. Enter the maximum wind velocity (knots) which may occur during normal port operations. Enter as a positive value regardless of direction.

7. Enter the ship type and deadweight tonnage of the least maneuverable vessel expected to utilize the waterway. This will normally be the ship with the largest dwt. Tug and tow and push barges are not presently considered for design purposes.

8. Enter the minimum expected transit speed for the vessel noted in line 7. If unknown, enter 4.0 knots as a worse case value.

9. Enter the maximum expected transit speed for the vessel noted in line 7. This will typically be the vessel's full ahead maneuvering speed, not its full capability sea speed.

10. Enter the length (feet) of the vessel noted in line 7.

11. Enter the beam (feet) of the vessel noted in line 7.

12. Circle the AN detection distance for which adequacy is to be determined. The AN detection distance is taken to be the distance at which 50 percent of the pilots will see the AN. Radio piloting techniques are assumed for detection distances less than the AN spacing. Visual piloting techniques are assumed for detection distances greater than the AN spacing.

13. Circle the daylight conditions for which the RRF is to be determined. Night, dusk, and dawn are conservatively assumed to be the same condition.

14. Circle the appropriate traffic condition.

15. Enter the value for maximum crosscurrent, VX, from line 5 and the minimum transit speed, VMIN, from line 8 in the positions indicated. Calculate the resultant drift angle, DA, as the inverse tangent of VX/VMIN. Enter the result on line 15.

16. Determine region distance from Table A-2 and enter. Complete line 3, if not already completed.

A.3 DETERMINE THE DIMENSION (DK) OF EACH TRACKKEEPING REGION

This section includes Form PPP that appears as Figure A-4 on which the user will report conditions for each individual trackkeeping region. Notice that if the adjoining recovery regions extend from turn to turn, there is no trackkeeping region in that straight channel segment: DK = 0. If Form PPP is to be used, there are instructions for filling in each line of the form. The numbered instructions correspond to the identical numbered boxes on the form. Table A-3 lists rules relating the reported conditions to the resulting dimensions. The dimensions may be recorded on Form PPP. Figure A-4 also shows a variety of alternative buoy arrangements that are discussed in Appendix B.

TABLE A-3. RULES DETERMINING THE DISTANCE (DK) OF EACH TRACKKEEPING REGION

Rule 1: After DR has been determined from each turn:	DK = the remainder of the straight segment.[11]

Instructions

1. Enter a written description of the channel and the waterway or port name.

2. Enter the NOAA chart number which provides a detailed diagram of the existing AN configuration and present bathometry (depth) and dimensions.

3. Enter the latitude and longitude of a point midway along the channel section and which is midway between the channel edges. (This may be done after the dimension of the region has been determined.)

4. Enter the channel width (feet) as indicated on the chart (or) the width of navigable water with regard to the maximum draft of the user vessels.

5. Enter the maximum current component which flows perpendicular to the channel edges. Enter as a positive value regardless of direction. If none expected, enter 0.0.

6. Enter the ship type and deadweight tonnage of the least maneuverable vessel expected to utilize the waterway. This will normally be the ship with the largest dwt. Tug and tow and push barges are not presently considered for design purposes.

8. Enter the minimum expected transit speed for the vessel noted in line 7. If unknown, enter 4.0 knots as a worse case value.

9. Enter the maximum expected transit speed for the vessel noted in line 7. This will typically be the vessel's full ahead maneuvering speed, not its full capability sea speed.

TRACK KEEPING REGION IDENTIFICATION — FORM PPP

1. TURN NAME AND LOCATION	2. CHART NO.
3. LATITUDE AND LONGITUDE OF REGION MIDPOINT	

CHANNEL AND ENVIRONMENTAL PARAMETERS

4. ENTER CHANNEL WIDTH (FEET)	W= FT
5. ENTER MAXIMUM CROSS CURRENT COMPONENT (KNOTS)	VX= KTS
6. ENTER MAXIMUM WIND VELOCITY (KNOTS)	VW= KTS

DESIGN VESSEL PARAMETERS

7. ENTER SHIP TYPE AND DWT	
8. ENTER MINIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMIN = KTS
9. ENTER MAXIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMAX= KTS
10. ENTER SHIPS LENGTH (FEET)	L= FT
11. ENTER SHIPS BEAM (FEET)	B= FT

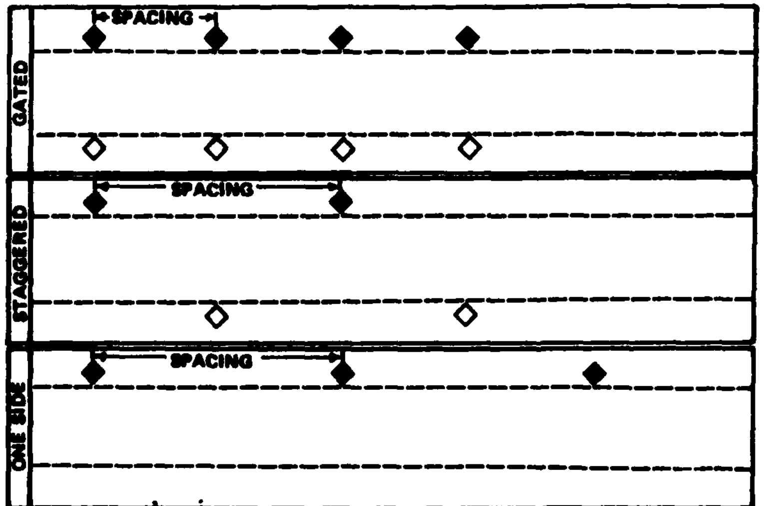
SRA DESIGN PARAMETERS (CIRCLE ONE)

12. AN DETECTION DISTANCE	LESS THAN AN SPACING (RADAR)	GREATER THAN AN SPACING (VISUAL)
13. DAYLIGHT CONDITIONS	DAY	NIGHT, DUSK OR DAWN
14. TRAFFIC	ONE WAY	TWO WAY
15. MAX EXPECTED DRIFT ANGLE TAN^{-1}(LINE 5 / LINE 8) =	DA = DEG	

DK = 16 ( ) DETERMINE FROM TABLE A.3

TRACK KEEPING REGION ADEQUATE CHANNEL MARKING (CIRCLE ONE)

SRA CONFIGURATION	GATED HIGH SENS. RANGE	STAGGERED	ONE SIDE LOW SENS. RANGE
AN SPACING	SHORT 5/8 TO 7/8 NM		LONG 7/8 TO 1 1/4 NM



RANGES

HIGH SENSITIVITY	LOW SENSITIVITY
$3.0<K<10.0$ *	$0.5<K<1.0$
$2<X_Q<8$ FT *	$25<X_Q<40$ FT

*SEE COAST GUARD PUBLICATION 308 FOR CALCULATION OF THE VALUES OF LATERAL SENSITIVITY K AND CROSSTRACK POSITION X FOR THE Θ_Q DISPLACEMENT (i.e., X_Q).

Figure A-4. Determine Distance (DK) of Trackkeeping Region: Form PPP

10. Enter the length (feet) of the vessel noted in line 7.

11. Enter the beam (feet) of the vessel noted in line 7.

12. Circle the AN detection distance for which adequacy is to be determined. The AN detection distance is taken to be the distance at which 50 percent of the pilots will see the AN. Radio piloting techniques are assumed for detection distances less than the AN spacing. Visual piloting techniques are assumed for detection distances greater than the AN spacing.

13. Circle the daylight conditions for which the RRF is to be determined. Night, dusk, and dawn are conservatively assumed to be the same condition.

14. Circle the appropriate traffic condition.

15. Enter the value for maximum crosscurrent, VX, from line 5 and the minimum transit speed, VMIN, from line 8 in the positions indicated. Calculate the resultant drift angle, DA, as the inverse tangent of VX/VMIN. Enter the result on line 15.

16. Determine region distance, DK, from Table A-3 and enter. Complete line 3, if not already completed.

A.4 AN ILLUSTRATIVE EXAMPLE

The channel selected to illustrate the process described here is the Baltimore Approach in Upper Chesapeake Bay.[12] An excerpt from the chart is presented as Figure A-5.[13] As a beginning, the subject channel is roughly marked off into regions as shown on Figure A-5. They include: each turn region, a recovery region adjacent to each turn in both directions, and potential trackkeeping regions in the middle of each channel segment.

A.4.1 The Turn Region

To illustrate the process of determining the distance of a turn region, the noncutoff turn closest to the beginning of the channel was selected. It is labeled "DT1" in Figure A-5. A completed Form NNN for this turn appears as Figure A-6. Based on Table A-1, DT1 = 0.50 nm in each direction.

A.4.2 The Recovery Region

To illustrate the process of determining the distance of a recovery region, the region above the turn in Section A.4.1 was selected. It is labeled "DR1" in Figure A-5. A completed Form OOO for this turn appears as Figure A-7. The conditions reported in the form include ships over 30,000 dwt, speeds over 6 knots, and two-way traffic. The rules in Table A-5 determine that DR1 extends from turn to turn.

A.4.3 The Trackkeeping Region

The potential trackkeeping region adjacent to the recovery region described in Section A.4.2 is labeled "DK1" in Figure A-5. Because the recovery region extends from turn to turn, DK1 = 0, according to Table A-3. No form is illustrated for this region.

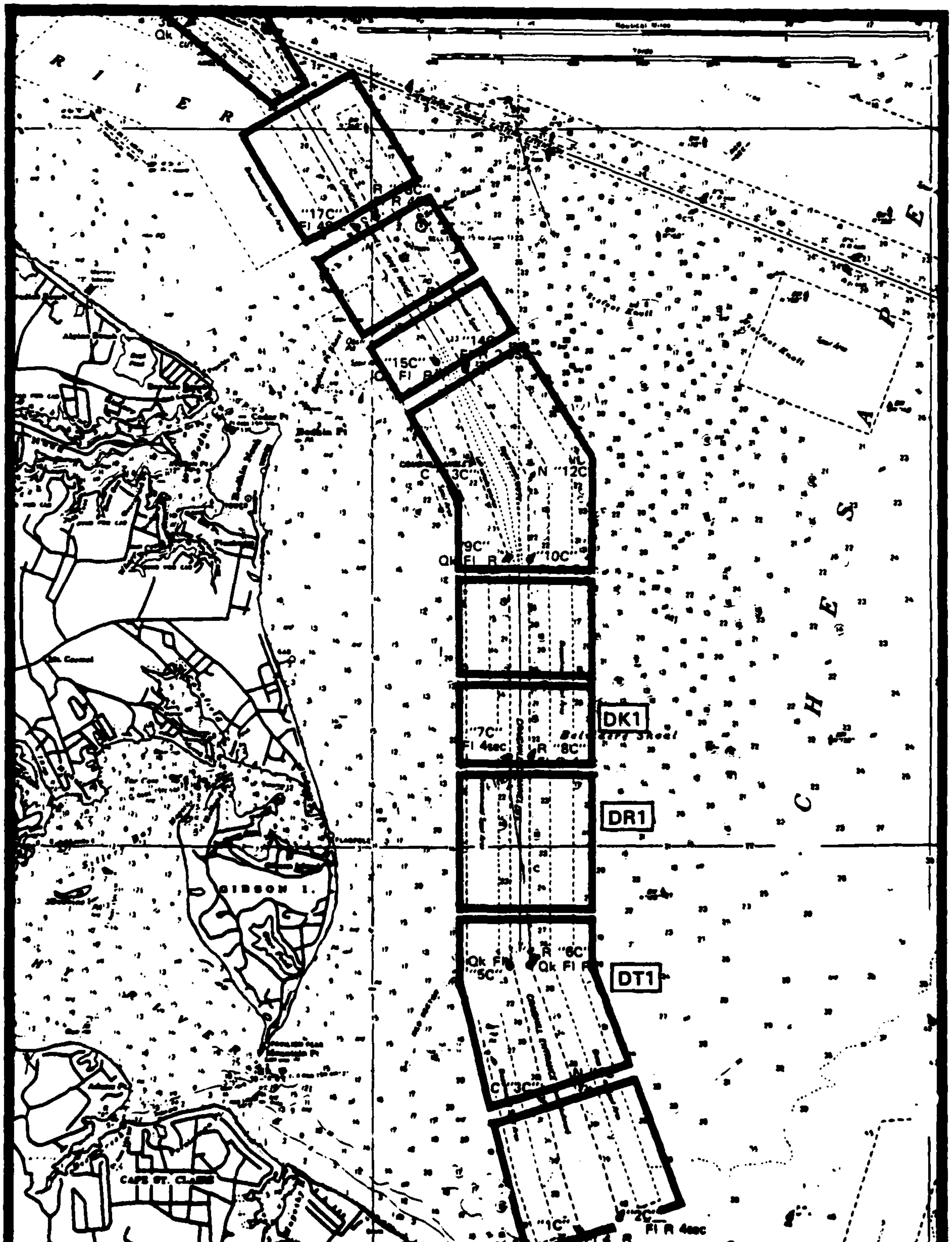


Figure A-5. A First Division of the Baltimore Approach Into Regions (Chart 12278, October 11, 1980, With Additions)

TURN REGION IDENTIFICATION FORM NNN

1. TURN NAME AND LOCATION CRAIGHILL CHNL, FIRST TURN	2. CHART NO. 12278
3. LATITUDE AND LONGITUDE OF TURN APEX 39° 4.2'N 76° 23.7'W	

CHANNEL AND ENVIRONMENTAL PARAMETERS

4. ENTER CHANNEL WIDTH (FEET)	W= 800 FT
5. ENTER MAXIMUM CROSS CURRENT COMPONENT (KNOTS)	VX= .5 KTS
6. ENTER MAXIMUM WIND VELOCITY (KNOTS)	VW= 25 KTS

DESIGN VESSEL PARAMETERS

7. ENTER SHIP TYPE AND DWT	Bulk / 130 K
8. ENTER MINIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMIN= 4 KTS
9. ENTER MAXIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMAX= 11 KTS
10. ENTER SHIPS LENGTH (FEET)	L= 810 FT
11. ENTER SHIPS BEAM (FEET)	B= 133 FT

SRA DESIGN PARAMETERS (CIRCLE ONE)

12. AN DETECTION DISTANCE	LESS THAN 1 NM (RADAR)	GREATER THAN 1 NM (VISUAL)
13. DAYLIGHT CONDITIONS	DAY	NIGHT, DUSK OR DAWN
14. TURN CONFIGURATIONS	NONCUTOFF	CUTOFF
15. TURN ANGLE	0 TO 20 DEG	20 TO 40 DEG
	GREATER THAN 40 DEG	
16. TRAFFIC	ONE WAY	TWO WAY

DETERMINE FROM TABLE A1
DT = 17 .5 NM (EACH) DIRECTION

ADEQUATE NUMBER OF TURN MARKINGS (CIRCLE ONE)

SRA CONFIGURATION				
	4 BUOYS	3 BUOYS	2 BUOYS	1 BUOY

ADEQUATE PLACEMENT OF TURN MARKINGS

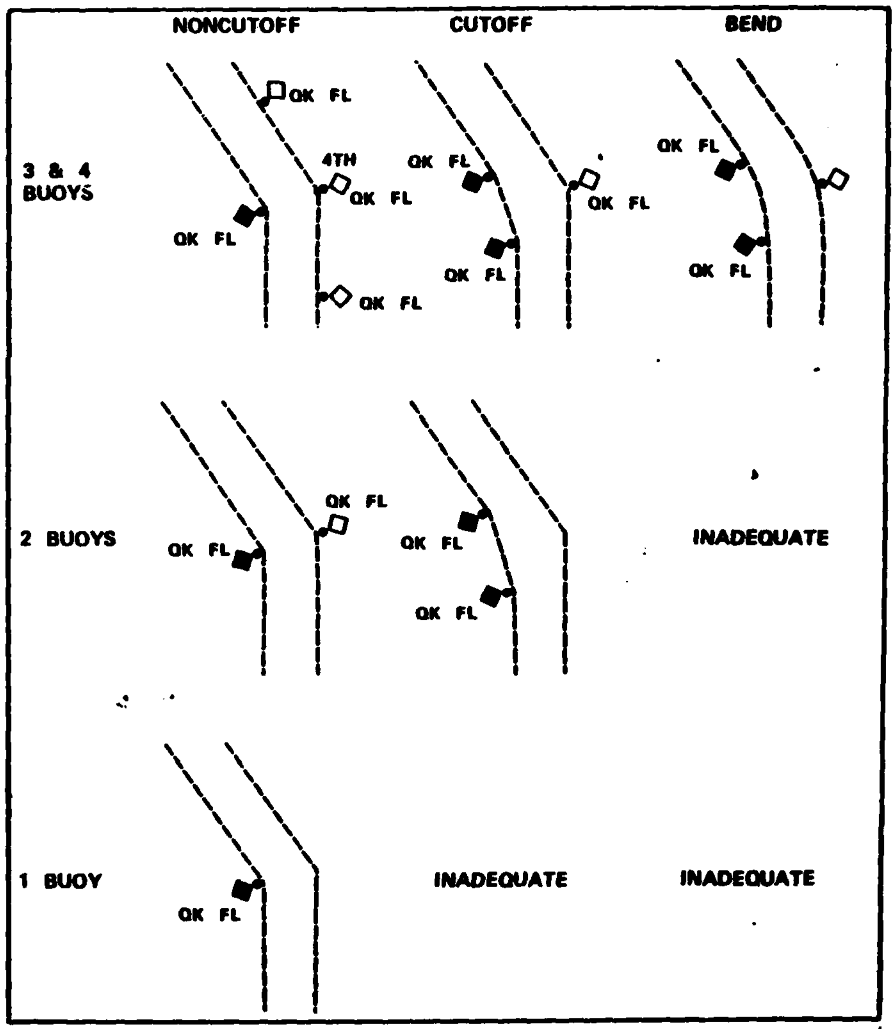


Figure A-6. Sample Determination of Turn Region Length, First Turn, Craighill Channel

RECOVERY REGION IDENTIFICATION

FORM 000

1. TURN NAME AND LOCATION: CRAIGHILL CHANNEL	2. CHART NO. 12278
3. LATITUDE AND LONGITUDE OF REGION MIDPOINT: 39° 5.8' N 76° 23.7' W	

CHANNEL AND ENVIRONMENTAL PARAMETERS

4. ENTER CHANNEL WIDTH (FEET)	W= 800 FT
5. ENTER MAXIMUM CROSS CURRENT COMPONENT (KNOTS)	VX= 0 KTS
6. ENTER MAXIMUM WIND VELOCITY (KNOTS)	VW= 25 KTS

DESIGN VESSEL PARAMETERS

7. ENTER SHIP TYPE AND DWT	BULK / 130 K
8. ENTER MINIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMIN= 4 KTS
9. ENTER MAXIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMAX= 11 KTS
10. ENTER SHIPS LENGTH (FEET)	L= 810 FT
11. ENTER SHIPS BEAM (FEET)	B= 133 FT

SRA DESIGN PARAMETERS (CIRCLE ONE)

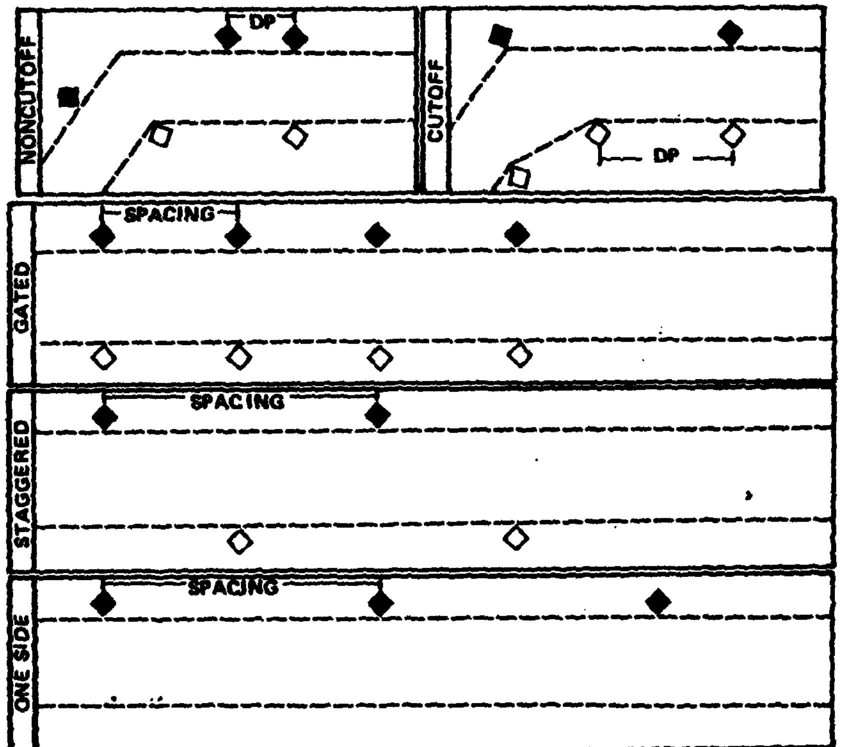
12. AN DETECTION DISTANCE	LESS THAN AN SPACING (RADAR)	GREATER THAN AN SPACING (VISUAL)
13. DAYLIGHT CONDITIONS	DAY	NIGHT, DUSK OR DAWN
14. TRAFFIC	ONE WAY	TWO WAY
15. MAX EXPECTED DRIFT ANGLE	TAN^{-1}(LINE 5 / LINE 8) = 0 / 4 =	DA = 0 DEG

DETERMINE FROM TABLE A.2

DR = 16 TURN (TO TURN)

RECOVERY REGION ADEQUATE CHANNEL MARKING (CIRCLE ONE)

MAXIMUM DISTANCE FROM TURN PULLOUT OR CUTOFF BUOY TO FIRST BUOY	D.P.≤ 3/8 NM		D≤ 5/8 NM
SRA CONFIGURATION	GATED HIGH SENS. RANGE	STAGGERED	ONE SIDE LOW SENS. RANGE
AN SPACING	SHORT 5/8 TO 7/8 NM		LONG 7/8 TO 1 1/4 NM



RANGES	HIGH SENSITIVITY	LOW SENSITIVITY
	3.0< K <10.0*	0.5< K <1.0
	2< Xa <6 FT*	25< Xq <40 FT

*SEE COAST GUARD PUBLICATION 388 FOR CALCULATION OF THE VALUES OF LATERAL SENSITIVITY K AND CROSSTRACK POSITION X FOR THE Θ_Q DISPLACEMENT (i.e., X_Q).

Figure A-7. Sample Determination of Recovery Region Length, Craighill Channel

EXPLANATORY NOTES FOR APPENDIX A

1. a. The selection of these factors for inclusion in the Aid to Navigation Systems performance study is discussed in Bertsche and Cook, Analysis of Variables.

   b. The results of the experimental evaluation of these factors are the topic of the several Principal Findings reports. Throughout this manual, when the results of these evaluations are used to make recommendations, there will be reference to the specific report and section that is relevant. This is the main purpose of the explanatory notes.

2. This rule is a simple definition of a cutoff turn.

3. This dimension, 0.50 nm in each direction is not arbitrary. It encloses the longest distance from the turn apex recommended for a pullout buoy (for limited conditions.) See Appendix B, Section B.1.1, Rule 3, and Explanatory Notes 8 through 15 for that section.

4. No bends were included in the experiment. This rule is an extrapolation from the more gradual movement of the ship through cutoff turns. A description of performance in cutoff and noncutoff turns appear in Smith and Bertsche, CAORF Principal Findings Report, Section 4.

5. An approach from the open sea appears in Bertsche, Atkins, and Smith, Ship Variables Principal Findings, Section 4 and in Appendix E. Because the pilot has the freedom to maneuver in "safe water" in choosing the ship's approach, the entrance is quite gradual. By the time the ship passes the first straight channel buoys, the track is relatively controlled (except for the large ship in low buoy density conditions — a combination that is not recommended).

6. The length of the recovery region specified is for a 35-degree noncutoff turn. When this distance is applied to a smaller angle turn or a noncutoff turn, the recommendations are probably conservative or cautious.

7. Bertsche, Atkins, and Smith, Ship Variables Principal Findings Report, Section 5, page 56 shows a graph comparing alongtrack performance for a 30,000 and 80,000 dwt ship. In Leg 2, the crosstrack standard deviation for the 30,000 dwt ship begins to decrease 0.85 nm from the turn point and is at its minimum at 1.17 nm. The 80,000 dwt ship begins to decrease at 1.17 nm and is at its minimum at 1.95 nm. Presumably, the decrease marks a consensus among pilots as to the track the ship is to take and the minimum indicates the final track. The mean here is not helpful in indicating settling on the track. It passes the centerline, apparently responding to current and wind effects.

8. Bertsche, Atkins, and Smith, Ship Variables Principal Findings Report, Section 5, page 69 compares performance for the 80,000 dwt

ship at 6 and 10 knots. At the 10-knot speed there is an oscillatory nature to the magnitude of the standard deviation. It seems each time the pilots make an adjustment (probably in response to passing buoys), it takes further adjustment to recover. The rule here is based on the conclusion that a large ship at a high speed is never really recovered.

9. As the scenarios were planned, it is at Data Line 15 in Leg 2 that the crosscurrent component has decreased to a point where only a 2-degree drift angle is required to compensate. In most of the scenarios run, it is at or about this point that the crosstrack mean of the transits approximates the centerline of the channel and that the standard deviation approximates its eventual minimum. An example of this efect is in Smith and Bertsche, Ship Variables on page E-9. This is a relatively unambiguous case that does not show the effects of larger ships, faster speeds, perturbing winds, or difficult buoy arrangements that tend to obscure the relationship of crosscurrent to piloting performance.

10. a. The only traffic condition run in any of the experiments was described in Smith and Bertsche, CAORF Principal Findings Report, Section 2. There, passing a predictable traffic ship with following wind and current proved to be such an easy problem that it has little generality.

    b. The Aids to Navigation Systems project included a data collection at sea under conditions as similar to the experiments as possible. Cooper, Cook, and Marino, At-Sea Data Collection Report, Section 3 reports on those channel transits that included traffic. The tracks of ships passing and overtaking traffic filled the width of the channel segments for their entire length.

11. At the beginning of Appendix A straight channel piloting performance was divided by definition into two processes: recovery/maneuvering and trackkeeping. Recovery/maneuvering performance is characterized by more-than-minimum crosstrack standard deviations and by crosstrack means displaced from the pilots' intended track. This division emphasizes the effects of factors that perturb the ship: turn, traffic, large ship size, high speed, crosscurrent or wind. Calling the response to these factors "recovery/maneuvering" implies that the need for aids will be relatively great. This is indeed the case. "Trackkeeping" is the absence of such factors. Application of Section 1 and Appendices B and C will demonstrate that relatively undemanding recovery conditions may require as few aids as would trackkeeping conditions.

12. This is the channel that was used for the related at-sea study described in Cooper, Cook, and Marino, At-Sea Data Collection. It was selected because of the breadth of information and data available.

13. United States - East Coast, Maryland, Chesapeake Bay, Approaches to Baltimore, Harbor, NOAA, Number 12278, October 11, 1980.

Appendix B

THE RECOMMENDATION OF ADEQUATE CONFIGURATIONS

The instructions in this appendix are based on the assumption that Appendix A has already been implemented. The configurations recommended as adequate here are based on the conditions specified. They may be inadequate for more demanding conditions or redundant for less demanding conditions. The recommendations are made region by region, but there is not complete independence. If the turn in the channel is not adequately marked as specified, recommended marking in the recovery region may not be adequate to compensate.[1] Similarly, if the recovery is not adequately marked, the trackkeeping region may not compensate. It is not possible to consider all irregular or nonconforming possibilities.[2]

The recommendations here are for arrangements of buoys as aids.[3] This specialization makes a number of assumptions:

- Any <u>fixed or floating aid</u> that is positioned at the channel edge is used in the same way by a pilot. "Buoy," here, can be taken to mean an aid at the channel edge.

- <u>Ranges</u> are dependent on detection distance for their use. Therefore, a channel marked with buoys must be adequately marked without consideration of the range.

- While pilots use <u>radar</u> to inspect a whole channel or harbor, they do not use it for moment-to-moment piloting decisions when buoys are visible. Therefore, buoys must be adequate to stand alone in relatively short detection distance. Recommendations here assume visual piloting is possible in detection distances as low as 3/4 to 1-1/2 nm.

B.1 EVALUATING THE TURN REGION

Turns are adequately marked if <u>all</u> the requirements outlined in Table B-1 are met.

B.1.1 <u>The Noncutoff Turn</u>

Turns in U.S. harbors appear as two basic configurations that are illustrated in Figure B-1. At the bottom of the figure is a "noncutoff" turn. Such abrupt turns comprise about one-third of turns in U.S. harbors. They tend to be of small angles (less than 20 degrees) and they are most frequently marked by very few buoys: one buoy at the turnpoint or inside apex; or a gate, buoys at both the inside and outside apexes.[4] The following requirements should be met for the marking of a noncutoff turn.

<u>Rule 1</u>: The <u>turnpoint</u>, or inside apex, should always be marked.[5]

<u>Rule 2</u>: The <u>outside apex</u> of the turn should be marked if there is a possibility of meeting traffic in the turn. Marking the space available for the turn allows the pilot to choose an alternate track through the

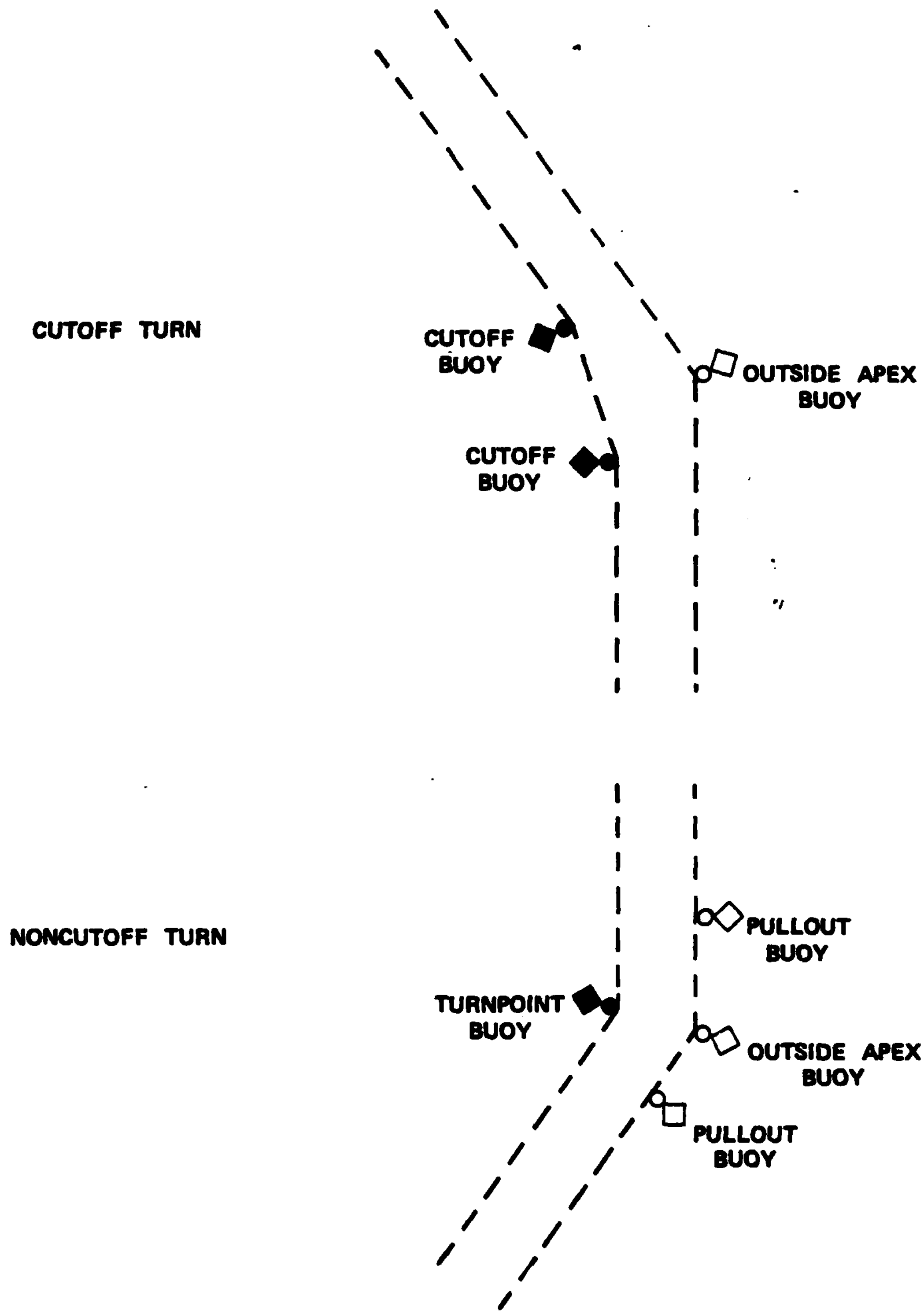


Figure B-1. Turn Configurations and Possible Buoy Placements

TABLE B-1. SUMMARY OF TURN REGIONS RULES

1. Noncutoffs • Turn point must always be marked. • Apex must be marked for traffic • Pullout must be marked with some variation allowed in distance from apex depending on conditions. 2. Cutoffs • Inside corners or cutoff must always be marked. • Apex must be marked for traffic. 3. Bends • Bends can be treated as cutoff turns.

turn.[6] The width of the channel is not a factor to consider in marking the turn. Pilots use a larger area in a wider channel, but not proportionally wider than is available.[7]

Rule 3: Pullout buoys -- that is, an additional buoy a short distance beyond the turnpoint and preferably to the outside of the turn -- should be provided in both directions. The following is a list of factors that determine the recommended distance from the turnpoint for the pullout buoy. The recommended maximums are outlined in Table B-2 and discussed below.

a. If the turn angle is greater than 15 degrees and one of the following is also true, the pullout buoys should be 0.25 nm or less from the turn point:[8]

- The channel is used for nighttime operations.[9]

- Ships of poor maneuverability or large size (over 30,000 dwt) use the channel.[10,11]

b. If the angle of the turn is greater than 15 degrees but none of the above conditions apply, the pullout buoy may be as far as 0.50 nm from the turnpoint buoys.[12]

c. If the turn is less than 15 degrees, the pullout buoy may be as far as 0.50 nm from the turn point.[13] Nighttime operations and the maneuverability, size, and speed of transiting ships need not be considered with small angle turns.[14]

d. Detection distance need not be considered provided it is sufficient to allow a view of the entire turn region.[15]

TABLE B-2. RECOMMENDED MAXIMUM DISTANCE FROM THE TURNPOINT FOR THE PULLOUT BUOY FOR NONCUTOFF TURNS

Ship Size	15 Degress or Less		More than 15 Degrees	
	Daytime Operation	Nighttime Operation	Daytime Operation	Nighttime Operation
30,000 dwt Vmax 6-10 knots	0.50 nm	0.50 nm	0.50 nm	0.25 nm
80,000 dwt Vmax 6-10 knots	0.50 nm	0.50 nm	0.25 nm	0.25 nm

B.1.2 The Cutoff Turn

Another third of turns in narrow channel are configured like that illustrated at the top of Figure B-1: with the inside corner dredged or widened to allow a more gradual turn. Such turns tend to be of larger angle (20 to 40 degrees) than the noncutoff turn. While these, too, are most frequently marked with only one or two buoys, they are more likely than noncutoff turns to have more than two buoys.[16] The performance study demonstrated a need for more than one or two buoys. Pilots negotiate such a turn differently than they do a noncutoff, treating them as a gradual turn or two minor turns. The buoys should outline all the available space to allow the pilots to make use of it and to avoid their cutting across an unmarked inside corner.

Rule 1: Both inside corners of the cutoff should be marked.[17]

Rule 2: The outside apex should be marked if there is a possibility of meeting traffic in the turn. This allows ships to choose an alternate track through the turn.[18]

Since this is a complete marking of the turn, other possible factors -- channel width,[19], detection distance[20] (assuming it is sufficient to allow a view of the whole turn area), day/night,[21] angle of turn,[22] and ship differences[23] - need not be considered.

B.1.3 Bends

One-third of turns in U.S. ports are actually gradual bends, frequently in a meandering river.[24] Because of the gradual nature of these transitions, the discussion of cutoff turns is more appropriately generalized to bends. If the pilot is to make maximum use of the area available, this area should be outlined for him. Aids should be adequate to discourage cutting across unmarked shoals on the inside of the bend.

B.2 MARKING THE RECOVERY REGION

A variety of straight channel aid configurations are illustrated in Figure B-2. These configurations are selected as frequent and representative of configurations in U.S. harbors.[25] They include gated buoys, arranged in pairs across the channel; staggered buoys, alternating sides of the channel; and one-side channel marking. Some variation in spacing or density (the number of buoys per unit distance) is also considered: from 5/8 to 1-1/4 nm along a single side.[26] In this discussion "short spacing" means 5/8 to 7/8 nm along a single side; "long spacing" means 7/8 to 1-1/4 nm along or single side. Spacings longer than 1-1/4 nm are not considered.

There is a relationship between configuration and spacing and the effectiveness of the piloting techniques they encourage. Gated buoys encourage the most consistent and accurate piloting techniques, funneling traffic into a relatively precise track. The precision resulting from gates is relatively insensitive to variation in spacing.[27] Staggered buoys are relatively less effective as aids. They encourage a wider variety of piloting techniques, some of which are less accurate and result in intermediate performance. The effectiveness of staggered buoys is sensitive to spacing.[28] In comparison one-side configurations are only marginally effective. They encourage the greatest variety of piloting techniques, some of which are inaccurate and result in poor piloting performance. The marginal effectiveness of one-side configurations is not improved by decreased spacing (or increased density).[29] One-side buoys are recommended only for channels too short to have a second staggered buoy.[30] Irregular configurations may be compared to the configuration they most resemble.

B.2.1 Adequate Distances from Turn Buoys to First Recovery Buoys

Channel width and aid configuration together determine the allowable distance to the first buoy or pair of buoys, as summarized in Table B-3. The relationship for the 500-foot wide channels are illustrated in Figure B-2.

Rule 1: For the narrower 500-foot channel, the first gate may be 5/8 nm from the pullout buoy regardless of later spacing.

Rule 2: For the narrower 500-foot channel, for staggered configurations the distance to the first buoy may be only 3/8 nm, regardless of later spacing.[31] These relationships are illustrated in Figure B-2. The longer permissible distance for the gated buoys is a consequence of their greater effectiveness as aids.

Rule 3: For the wider 800-foot channel, 5/8 nm to the first buoy or pair of buoys is adequate, for both gated or staggered configurations.[32]

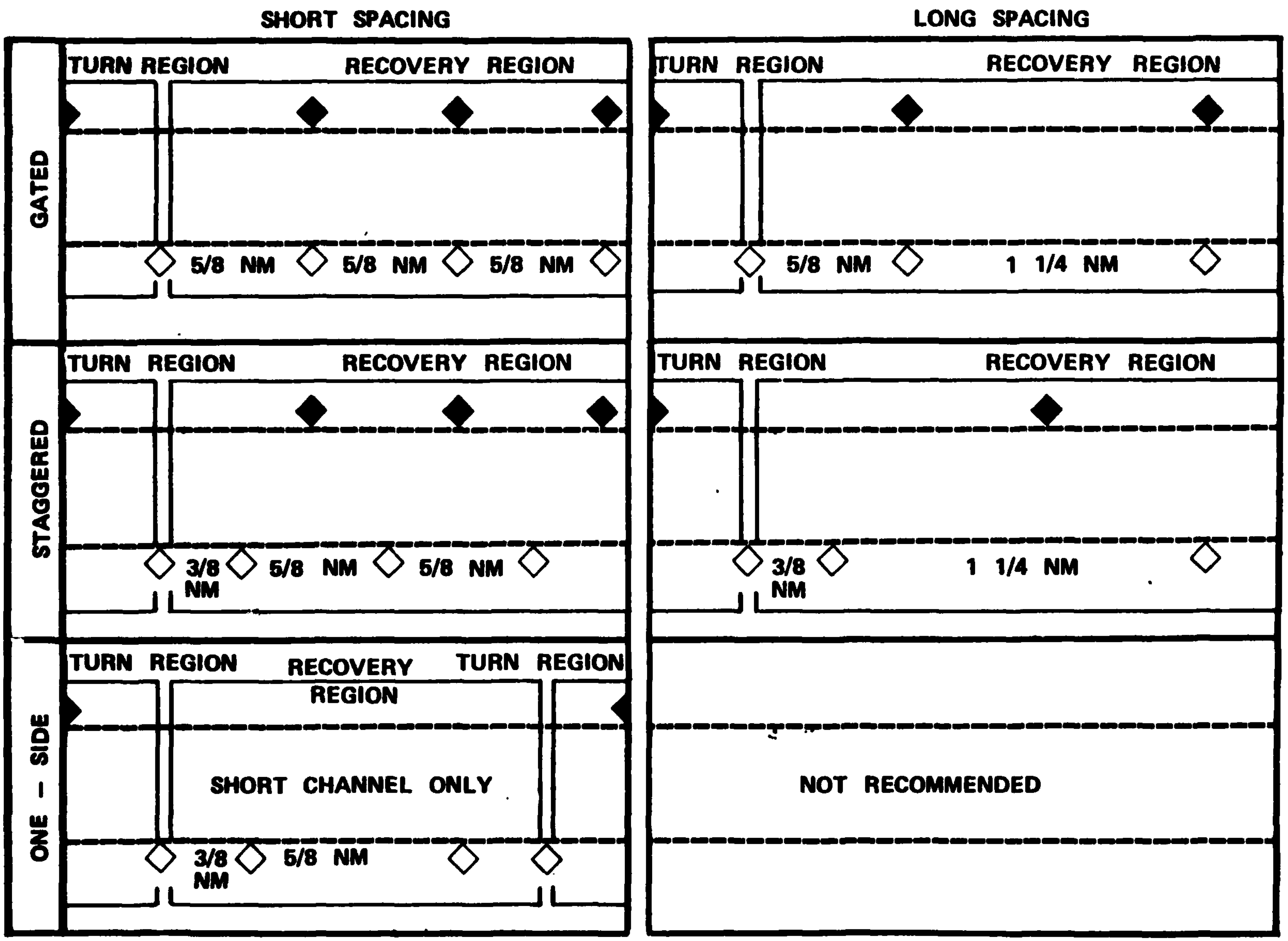


Figure B-2. Alternative Arrangements and Spacing of Straight Channel Buoys for 500-Foot Channels

TABLE B-3. DEFINITIONS OF ALTERNATIVE ARRANGEMENTS

Configuration	500-Foot Wide Channel	800-Foot Wide Channel
Gated configuration/ short spacing	From pullout buoy to first pair can be up to 5/8 nm	From pullout buoy to first pair can be up to 5/8 nm
	Later pairs can be up to 5/8 nm	Later pairs can be up to 5/8 nm
Gated configuration/ long spacing	From pullout buoy to first pair can be up to 5/8 nm	From pullout buoy to first pair can be up to 5/8 nm
	Later pairs can be up to 1-1/4 nm	Later pairs can be up to 1-1/4 nm
Staggered configurations/ short spacing	From pullout boy to first single buoy can be up to 3/8 nm	From pullout buoy to first single buoy single buoy (on either side) can be up to 5/8 nm
	Later buoys on alternate sides can be at an alongtrack distance of up to 3/8 nm or a one-side distance of 5/8 nm	Later buoys on alternate sides can be at an alongtrack distance of up to 3/8 nm or a one-side distance of 5/8 nm
Staggered configuration/ long spacing	From pullout buoy to first single buoy can be up to 3/8 nm	From pullout buoy to first single buoy single buoy can be up to 5/8 nm
	Later buoys on alternate sides can be at an alongtrack distance of up to 5/8 nm or on a one-side distance of 1-1/4 nm	Later buoys on alternate sides can be at an alongtrack distance of up to 5/8 nm or one a one-side distance of 1-1/4 nm
One-side channel configuration	These are acceptable only when the channel is too short to require a second staggered buoy	These are acceptable only when the channel is too short to require a second staggered buoy
Irregular configurations	These should be compared to the regular configuration they most resemble they most resemble	These should be compared to the regular configuration they most resemble they most resemble

B.2.2 Adequate Configuration and Spacing of Recovery Region Buoys

The following is a consideration of the conditions that affect piloting performance in the recovery region and the configurations that are required as adequate for these conditions. These relationships are summarized in Table B-4. If long spacing is indicated as adequate, short spacing is understood to be adequate as well, but redundant. Notice that once the maximum marking of short-spaced gates is required, it is not necesary to continue the list.

Rule 1: For 500-foot wide channels and 1-1/2 nm detection distance:

a. Except for the conditions listed below, either gated or staggered configurations with long spacing are adequate.[33]

b. Ships larger than 30,000 dwt transiting at any speed require short-spaced gates or staggered buoys.[34]

c. Current not parallel to the track that requires a compensating drift angle of 2 to 5 degrees requires long-spaced gates.[35]

d. Wind that is strong (35 knots or more), not parallel to the track, and gusting unpredictably, requires short spacing with either gated or staggered configurations.[36]

e. Traffic that causes the ship to change its track requires long-spaced gated buoys or short-spaced staggered buoys.[37]

Rule 2: For 800-foot wide channels and 1-1/2 nm detection distance:

a. Except for the conditions listed below, either gated or staggered configurations with long spacing are adequate.[38]

b. Ships larger than 30,000 dwt, transiting at any speed, require long-spaced gates or short-spaced staggered buoys.[39]

c. Current not parallel to the track that requires a compensating drift angle of 2 to 5 degrees requires long-spaced gates or short-spaced staggered buoys.[40]

d. Wind does not require an adjustment from the basic configuration.[41]

e. Traffic requires no adjustment, with the wider 800-foot channel.[42]

Rule 3: For 500-foot wide channels and 3/4 nm detection distance:[43,44,45,46]

a. Except for the conditions listed below, the requirement is for short-spaced gates or long-spaced staggered configurations.

b. Ships larger than 30,000 dwt transiting at any speed require short-spaced gates or staggered buoys.

TABLE B-4. SUMMARY OF RECOVERY CONDITIONS AND REQUIRED ADEQUATE CONFIGURATIONS*

With 1-1/2 nm or More Detection Distance

Condition	500-foot Channels	800-foot Channels
Except for conditions below	Gated or staggered, long spacing	Gated or staggered, long spacing
Ships larger than 30,000 dwt	Gated or staggered, short spacing	Gated, long spacing Staggered, short spacing
Current requiring drift angle of 2 to 5 degrees	Gated, long spacing	Gated, long spacing Staggered, short spacing
Wind: strong, gusting and perpendicular to track	Gated or staggered, short spacing	Gated or staggered, long spacing
Traffic	Gated, long spacing Staggered, short spacing	Gated or staggered, long spacing

With 3/4 nm Detection Distance

Condition	500-foot Channels	800-foot Channels
Except for conditions below	Gated, short spacing Staggered, long spacing	Gated, short spacing Staggered, long spacing
Ships larger than 30,000 dwt dwt	Gated or staggered, short spacing	Gated or staggered, short spacing
Current requiring drift angle of	Gated, short spacing	Gated or staggered, short spacing
Wind: strong, gusting, and and prependicular to track	Gated or staggered, short spacing	Gated, short spacing Staggered, long spacing
Traffic	Gated or staggered, short spacing	Gated, short spacing Staggered, long spacing

*If long spacing is indicated as adequate, short spacing is understood to be adequate, but redundant.

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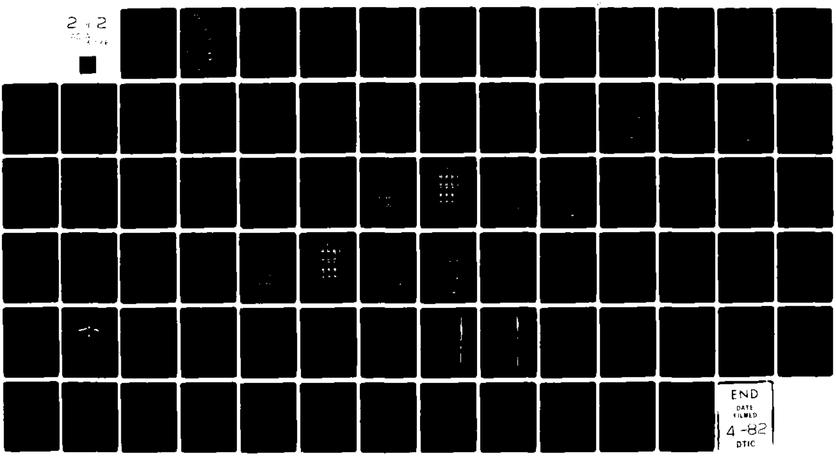
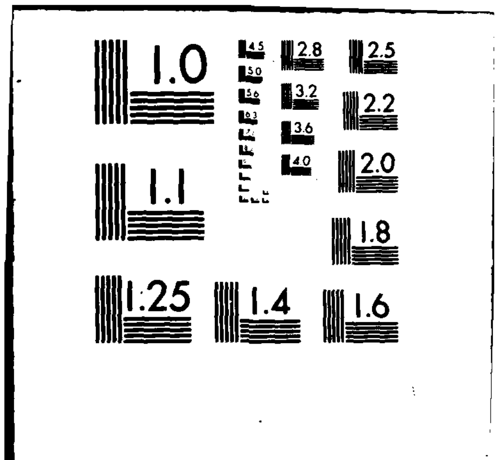
UNCLASSIFIED EA-80-U-035 USCG-D-77-81 NL





MICROCOPY RESOLUTION TEST CHART

c. Current not parallel to the track that requires a compensating drift angle of 2 to 5 degrees requires short-spaced gates.

d. Wind that is strong (35 knots or more), not parallel to the track, and gusting unpredictably, requires short spacing either gated or staggered configurations.

e. Traffic that causes the ship to change its track requires short-spaced gated buoys or staggered buoys.

Rule 4: For 800-foot channels and 3/4 nm detection distance:[47]

a. Except for the conditions listed below, the requirement is for short-spaced gates or long-spaced staggered configurations.

b. Ships larger than 30,000 dwt transiting at any speed require short-spaced gates or staggered buoys.

c. Current not parallel to the track that requires a compensating drift angle of 2 to 5 degrees requires short-spaced gates or staggered buoys.

d. Wind that is strong (35 knots or more), not parallel to the track, and gusting unpredictably, requires short-spaced gates or long-spaced staggered buoys.

e. Traffic that causes the ship to change its track requires short-spaced gates or long-spaced staggered buoys.

Rule 5: The following factors need not be considered in marking the recovery region.

a. Intended track has no effect on the need for buoys. (See traffic requirements.)[48]

b. Day/night differences have no effect on the need for buoys in the recovery region.[49]

B.3 MARKING THE TRACKKEEPING REGION

The conditions that extend the length of the recovery region do not have to be considered in marking the trackkeeping region. These include:

- crosscurrent requiring a compensating drift angle of 2 to 5 degrees,
- traffic requiring a change in track,
- ships larger than 30,000 dwt at speeds higher than 6 knots.

Since these are conditions that also have major effects on the need for buoys; with them eliminated, the need for buoys is considerably reduced.

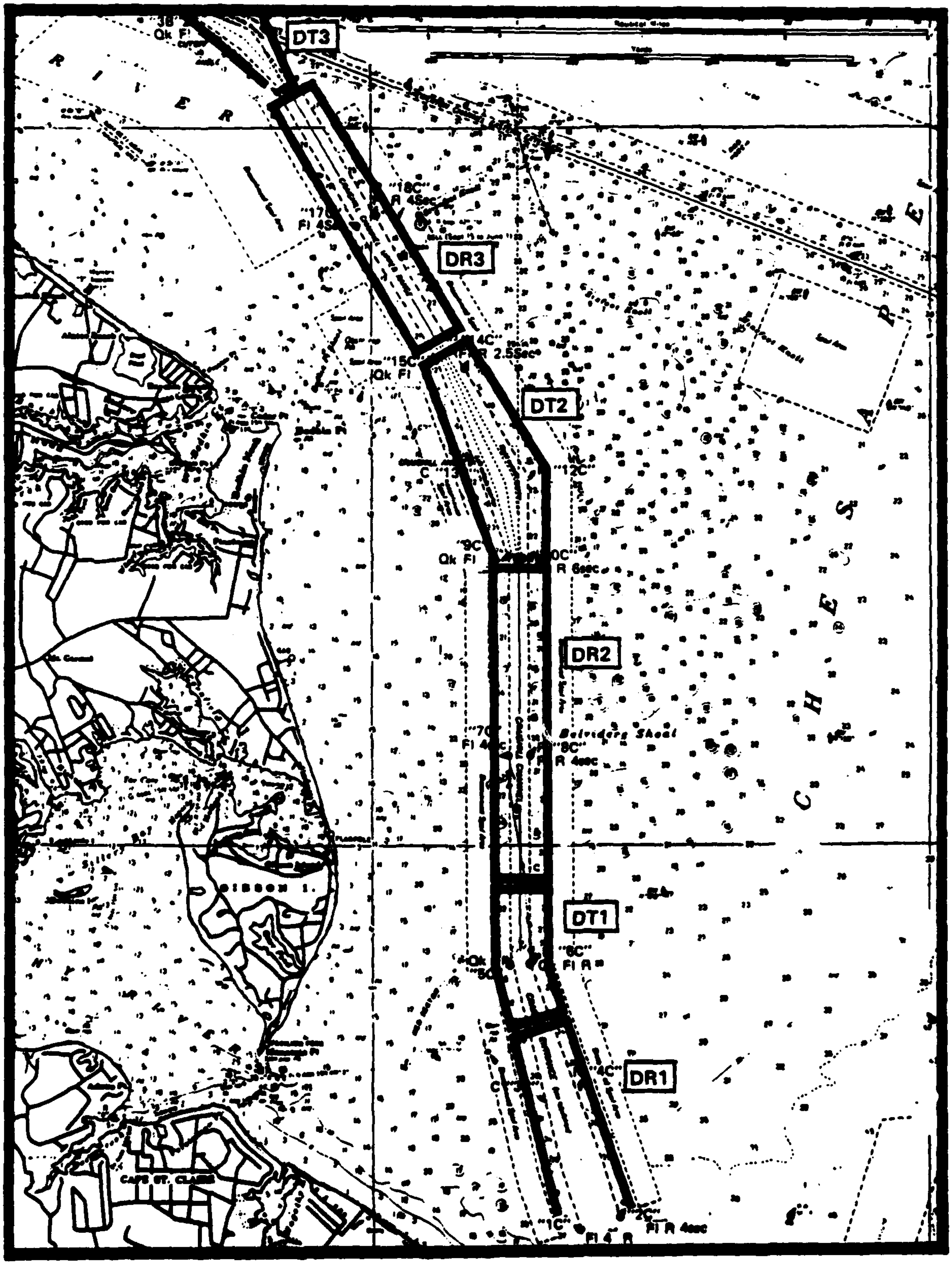


Figure B-3. Regions in Baltimore Harbor
(Chart 12278, October 11, 1980, With Additions)

Rule 1: For the trackkeeping region, long spacing with either a gated or staggered configuration is adequate.[50]

a. Large ships at 6 knots requires no adjustment to the basic configuration.[51]

b. Crosswind requires no adjustment.[52]

c. Nighttime operations requires no adjustment.[53]

d. Channel width requires no adjustment.[54]

e. Detection distance requires no adjustment.[55]

B.4 AN ILLUSTRATIVE EXAMPLE

The approach to Baltimore Harbor[56] is used here as an illustration of the process of recommending adequate configurations for channel conditions. This recommendation of adequate configurations is all this appendix purports to do. Section 2 suggests comparison of these recommendations with existing aids and the consideration of modifications to them as additional steps. Because this example is not continued in Section 2, this comparison will be made here.

An excerpt from the chart of Baltimore Harbor[57] is reproduced here as Figure B-3 with the turn and recovery regions to be discussed, outlined and numbered. A summary of conditions in the channel and the process that established the regions is available in Appendix A, Section A-4.

B.4.1 The Turn Regions

Taking the turns from the bottom, DT1 is a noncutoff turn of 18 degrees. The recommendation of Table B-1 is that the inside turnpoint be marked for any noncutoff turn. Because of the two-way traffic, the outside apex should be marked as well. A pullout buoy in each direction is recommended. Because the angle of turn is greater than 15 degrees, the channel is used for nighttime operations, and there are large ships transiting at relatively high speeds; the recommendation of Table B-2 is for a pullout buoy in each direction at a distance of 0.25 nm. In other words, a four-buoy turn is recommended. The other turns, DT2 and DT3, are cutoffs with traffic for which three buoys are recommended: at the apex and at the ends of the cutoff.

Inspection of Figure B-3 shows that the turns [illegible] not marked as recommended. The noncutoff turn, DT1, is marked wi[illegible]ate ("5C" and "6C"); but there are no pullout buoys. The next gate [illegible]7C" and "8C") in-bound is almost 1.50 nm beyond the apex. Perhaps the intention is to depend on the range to supplement the distant gate. This intention is suggested by the presence of a gate ("3C" and "4C") in the outbound direction away from the range only 0.75 nm from the apex. The assumption in this manual is that buoys must be adequate without ranges which require long detection distances: here, the back light of

Craighill Channel Range is almost 10 nm from turn DT1. Are the buoys adequate without the range? Notice first that the angle of turn is 18 degrees, not meaningfully different from the 15 degree turn considered a relatively unperturbing turn in the recommendations. Second, the channel here is a relatively wide 800 feet. Apparently the small angle and the width together constitute a relatively unperturbing turn.[58] This combination is probably adequate. Section 3 presents a technique for calculating a relative risk factor for this marking versus competing possibilities. (An earlier chart[59] for the area showed a gate 0.70 nm inbound beyond the apex, close to the 0.50 nm recommended for 15 degree turns.)

The first cutoff turn, DT2, is marked with six buoys ("9C" through "15C"). This is a redundant number by the recommendations here. Notice that the cutoff is very large: 1.54 nm long and 1950 feet wide. It is probably not meaningful to consider it a "turn". The extra buoys are marking another channel segment, one that requires course changes.[60] The marking of this turn is certainly adequate.

The last cutoff turn, DT3, is ambiguous. It is outlined by the three recommended buoys ("19C", "20C", and "3B"), but because of the intersection with the Brewerton Channel Eastern Extension, there is a fourth buoy ("2B"). The three recommended buoys make it adequate.

B.4.2 The Recovery Region

Because of the traffic and of large ships transiting at high speeds, the straight segments are entirely recovery regions, according to Appendix A. By the recommendations of Table B-4, this combination in an 800-foot channel requires long-spaced gates. According to Table B-3, this means 5/8 nm from the turn pullout buoys for the first gate and 1 1/4 nm for later gates.

Figure B-3 illustrates the existing marking. In DR1, Craighill Entrance has short-spacing between the gates ("1C" and "2C" to "3C" and "4C") providing well for the recovery from the entrance. DR2 is a problem. Since there is no pullout buoy in DT1, it is not clear from where to measure the distance to the first recovery buoy: the distance is almost 1.50 nm from the gate or just under 1 nm from the distance designated as turn region. As suggested in B.4.1, the low angle of turn and the width of the channel probably result in accommodation of the perturbation. However, a potential inadequacy is indicated in the placement of the first gate north of turn DT1. Again, an analysis of the relative risk factor of these conditions is suggested as described in Section 3 and Appendix C. The long-spacing is adequate for the length of the DR2 recovery region. In DR3, the first buoy beyond the turn is approximately 1 nm. This is longer than recommended, but certainly adequate after that very large cutoff. The 1 nm spacing is adequate for the rest of the recovery region.

EXPLANATORY NOTES FOR APPENDIX B

1. a. For Bertsche and Mercer, 32 Ports Analysis, the articulation between turnmarking and straight channel marking was not considered in the preparation of the report. There is no analysis of the relationship between buoys in the turn and buoys (or other aids) beyond.

   b. During experimentation, very little attention was given to a tradeoff between the two areas. The exceptions are in the CAORF Principal Findings Report, Section 4.7, and the Channel Width Principal Findings Report, Section 2.3.

2. A preparatory step in the project was reported as Bertsche and Mercer, 32 Major U.S. Ports. A survey of ports ensured that the experimental conditions were representative of real and frequent conditions. Infrequent, low-density conditions were sometimes tested for possible savings in channel marking. They were generally found to be inadequate for conditions. Examples of inadequate low density conditions are one-buoy cutoff turns and the long-spaced gates in the CAORF experiment; the long-spaced staggered buoys in 500-foot wide channels in the Channel Width experiment; and the one-side channel marking conditions in the One-Side experiment.

3. The results of the performance of aids to navigation systems project to date suggests that buoys are not sufficiently appreciated as aids. True, they are not reliably on station; but radar can be used to examine a whole channel ahead for the pattern formed by the buoys, and pilots in a busy harbor are likely to know if buoys have moved. Assuming the buoys are where they should be, they are a necessary, all-purpose aid. Even when the detection distance is long enough to see a range, it is problematic how effective that range is for turning or for maneuvering to pass or overtake traffic near the edge of the channel where the sensitivity is low. (See Marino, Smith, and Bertsche, Range Light Principal Findings Report.) Such maneuvering may require augmentation by buoys. With intermediate levels of detection distance the range is useless, the buoys are essential, and the radar is probably used by only a few pilots for actual minute-to-minute control decisions. When the detection distance is so low that the pilot cannot see the next buoy or gate, radar is essential. Even then pilots probably make use of the buoys -- along with other features -- to estimate their position and velocity in the channel.

(NOTE: In any of the Aids to Navigation experiments, detection distance is equal to visibility.)

4. Bertsche and Mercer, 32 Ports, Sections 3 and 5.

5. Smith and Bertsche, CAORF Principal Findings, Section 4.

6. a. Smith and Gaffney, Findings . . . Tampa Bay, Section 1 first discussed this need.
   b. Smith and Bertsche, Channel Width Principal Findings, Section 5.1 discusses the pilot's use of relatively close-on-board buoys.

7. Smith and Bertsche, Channel Width Principal Findings Report, Section 4.1.

8. CAORF Preliminary Performance Data, Vol. 6, Section 2: Notice that performance for the 15-degree turns is adequate under all conditions while this is not the case for the 35-degree turns. The latter require a pullout buoy which here is less than 0.25 nm from the turn point.

9. CAORF Preliminary Performance Data, Vol. 6, Section 2: The 35-degree turns require the pullout buoy for nighttime conditions.

10. Bertsche, Atkins, and Smith: Ship Variables Principal Findings, Section 4.4: The larger 80,000 dwt ship requires the closer pullout buoy.

11. Bertsche, Atkins, and Smith: Ship Variables Principal Findings, Section 5.3: Pullout performance is even poorer with the larger ship at the higher speed. The separation of large ships (Note 10) and large ships at high speeds only appears redundant because of the nonquantitative nature of the treatment here. Notice that in Appendix C there are two independent correction factors for these two effects. A large ship at a high speed places more of a demand on the need for aids than does a large ship alone.

12. CAORF Preliminary Performance Data, Vol. 6, Section 2: The 35-degree turn does not require the pullout buoy for daytime conditions.

13. a. CAORF Preliminary Performance Data, Vol. 6, Section 2 shows the pullout buoy before 0.25 nm is not necessary with the 15-degree turn.

    b. An inspection of individual scenarios in CAORF Preliminary Performance Data, Vol. 2, Section 2 supports an alternative distance for the pullout buoy.
       - The 0.50 nm distance is only adequate in the daytime for the 35-degree turn: Scenarios 21 and 25 versus 22 and 26.
       - The 0.50 nm distance is adequate day or night for the 15-degree turn: Scenarios 1, 2, 13, and 14.
       - A longer, 0.85 nm distance is not adequate for even the 15-degree turn: Scenarios 7, 8, 11, and 12.

14. a. CAORF Preliminary Performance Data, Vol. 6, Section 2 shows no difficulty with nighttime operations in 15-degree turns.

    b. The statement that ship effects need not be considered in marking small angle turns is an inference that follows from the

assumptions that the 30,000 dwt tanker used in the CAORF experiment was difficult to maneuver, and that if it did not have difficulty with one buoy marking a 15-degree turn, such a condition is not difficult. An conflictng chain of logic is that if 15-degree turns were not evaluated with a variety of ships, the results of running a variety of ships in 35-degree turns should be generalized. In this case, the 15-degree turns should, like the 35-degree turns, be marked with a pullout buoy before 0.25 nm if large ships are to use the channel.

15. CAORF Preliminary Perfomance Data, Vol. 5, Section 5: Once the effects of day and night are accounted for, there seems to be no residual effect of detection distance in the turns. Day/night and visibility/detection distances are confounded in this design making it difficult to separate the effects. The pattern of confounding is described on page 5-2 of that report. For the present purpose what is wanted are comparisons in which the two variables work against each other (day at 3/4 nm detection distance). The first comparison on page 5-3 is suitable: "15 DEG * NONCUTOFF * 1 BUOY * DAY VS NIGHT." Day has a 3/4 nm detection distance. Inspection of the track plot shows that day performance is better in the turn as indexed by both the means and standard deviations, despite the lower detection distance for day. The low detection distance does not seem to have an effect in the turn for the dimensions evaluated.

16. Bertsche and Mercer, 32 Ports, Sections 3 and 5.

17. CAORF Preliminary Performance Data, Vol. 6, Section 2: Notice that both 15 and 35-degree turns for both day and night need the insides of the cutoffs marked to protect those insides. Notice also that the 35-degree nighttime condition needs the inside marked to keep the distribution from going out on the outside. Apparently, the inside marking gives the pilot crosstrack information.

18. a. Smith and Gaffney, Findings . . . Tampa Bay, Section 1.

    b. Smith and Bertsche, Channel Width Principal Findings Report, Section 5 concluded that closeness of track to channel edge is compensated for by greater certainty of location of buoys and edges.

    c. Cooper, Cook, and Marino, At-Sea Data Collection shows a slight pilot preference for passing in a very large cutoff.

19. Smith and Bertsche, Channel Width Principal Findings Reort, Section 4 concluded that while pilots take more room in a wide channel, the extra room is not proportional to the extra space available. Rules for making turns in narrow channels (500 feet) are applicable to wider channels.

20. CAORF Preliminary Performance Data, Vol. 5, Section 5: Day/night and detection distance are confounded in this design making it difficult to separate the effects. The pattern of confounding is

described on page 5-2 there. For the present purpose what is wanted are comparisons in which the two variables work against each other (day at 3/4 nm detection distance) and there is only one buoy in the turn so tht extra buoys do not compensate for low detection distace. The plot on page 5-9 is suitable: "35 DEG * CUTOFF * 1 BUOY * DAY VS NIGHT." Day is at 3/4 nm detection distance. Day is better in the turn as indicated by both the means and standard deviation - low detection distance does not seem to have an effect in the turn. This is despite the fact that one of the two day, 3/4 nm detection distance scenarios (Scenario 31) requires the pilot to turn without seeing anything ahead (for less than a minute).

21. CAORF *Preliminary Performance Data*, Vol. 5, Section 5. (See Explanatory Note 17 above.) A comparison of the plot on page 5-9, "35 DEG * CUTOFF * 1 BUOY * DAY VS NIGHT," with that on page 5-10, "35 DEG * CUTOFF * 3 BUOYS * DAY VS NIGHT," shows that the three buoys improve the turn performance for both day and night, ameliorating the absolutely poor performance at night.

22. a. CAORF Preliminary Performance Data, Vol. 2, Section 5. A comparison of the plot on page 5-3, "15 DEG CUTOFF * 1 BUOY VS 3 BUOYS," and that on page 5-5, "35 DEG CUTOFF * 1 BUOY VS 3 BUOY," shows that the three buoys in the cutoff turn improves the 35-degree turn as it does the 15-degree turn.

    b. CAORF Preliminary Performance Data, Vol. 6, Section 3. A comparison of page 3-8, "35 DEG * CUTOFF * 1 BUOY," and page 3-9, "35 DEG * CUTOFF * 3 BUOYS," shows that three buoys in a 35-degree cutoff results in very controlled performance.

23. Ship variables were never varied with lower-angle turns (15 degrees) or with cutoff configurations. Fifteen-degree turns should not be a greater problem. The *Ship Variables Principal Findings Report*, Section 4, concluded that 35-degree noncutoff turns could be adequately negotiated by larger ships (80,000 dwt) if they were well marked. If there was no pullout buoy, the larger ship tended to go out. Should a larger ship have a pullout buoy even in a cutoff turn?

    a. If it is assumed that a cutoff is not negotiated as a single abrupt turn, but as a gradual turn or as two shallower turns: no.

    b. If it is assumed that the 30,000 dwt ship used at CAORF was a difficult ship and represents difficult ships: no.

24. Bertsche and Mercer, 32 Ports, Section 3.

25. See Bertsche and Mercer, 32 Major U.S. Ports, Section 4.

26. Bertsche and Mercer, 32 Major U.S. Ports, Section 4 reports that the mean alongtrack distance for all configurations is 3/4 nm.

27. This is a major conclusion in Smith and Bertsche, CAORF Principal Findings, Section 3; and Smith and Bertsche, Channel Width Principal Findings, Section 2.

28. Ibid.

29. This is a major conclusion of Marino, Smith, and Bertsche, One Side Channel Marking Principal Findings, Section 2.

30. Bertsche and Mercer, 32 Major U.S. Ports, Section 4 reports that one-side configurations tend to appear in shorter channels. The experiments vindicate this real-world usage - or vice versa.

31. a. These distances to the first buoy are the result of examining the marking-by-spacing interaction in Channel Width Preliminary Data Analysis, pp 2.1-11 to 2.1-14. Notice the recovery with both long- and short-spaced gates is adequate but only the short-spaced staggered is thus.

    b. The question remains as to whether the first staggered buoy should be to the inside or outside of the turn, and whether this factor has a relationship to spacing. A number of scenarios are available with buoys to the outside: there is adequate performance with a buoy to the outside approximately 3/8 nm from the apex in CAORF Scenario 18, Channel Width Scenario 1, and One-Side Scenario 5. With longer spacing to the outside in Channel Width Scenario 3, performance is adequate. In One- Side Scenarios 2 and 4, performance with that buoy to the inside is inadequate with either spacing. A possible mechanism for the adequacy of the close single buoy to the outside of the turn may be its availability with the pullout buoy to mark the outside edge of the channel. (There are other scenarios in the CAORF and One-side experiments where extremely restricted detection distance requires special interpretation)

    c. There are not sufficient conditions with the larger, 80,000 dwt ship and a variety of aid configurations to know if ship size affects the required distance to the first buoy beyond the pullout.

32. a. This recommended distance to the first buoy for 800-foot channels is suppoted by the Channel Width Preliminary Data Analysis, pp 2.2-6 and 2.2-7 which shows adequate recovery with both staggered and gated configurations beginning at 5/8 nm from the pullout.

    b. There are no conditions with 800-foot channels and 80,000 dwt ships to know if these two factors together influence the needed distance to the first recovery buoy.

33. The project did not include recovery after a turn without the added perturbation of crosswind and crosscurrent. It is necessary to make assumptions about the nature of such a recovery. The 30,000 dwt

ship demonstrated track-changing and trackkeeping in Leg 1 under a variety of aid conditions (see any of the experiments) with no difficulty and very little difference among the conditions. From this it is assumed that it would have little difficulty recovering from a well-marked turn without the crosswind and crosscurrent. The same assumption cannot be made about the 80,000 dwt ship. In Bertsche, Atkins, and Smith, Section 4, it is reported that it had difficulty entering the channel from the open sea - a gradual maneuver - without the crosswind and crosscurrent with the aid of long-spaced staggered buoys. Higher buoy density is recommended for the larger ship.

34. a. In Bertsche, Atkins, and Smith, Ship Variables Principal Findings, Section 4, it is reported that the 80,000 dwt ship is dependent on the short-spaced gates for recovery, having difficulty with the long-spaced, staggered buoys. The larger ship seemed to have a greater tendency to approach each alternate buoy as can be seen in Appendix E, Scenario 6 of the report. It is possible that long-spaced gates would be acceptable for the larger ship, but this is unlikely. The comparison between the two ships on page 55 shows that the larger ship must go a greater distance or through more gates to settle. If the number of gates, in addition to the distance, plays a role; long-spaced gates may lengthen the process of settling.

b. The 80,000 dwt ship was never run with short-spaced staggered buoys. This requirement is supported by analogy with behavior of the 30,000 dwt ship with a variety of straight channel markings as described in Smith and Bertsche, Channel Width Principal Findings, Section 2. The 30,000 dwt ship did approach each long-spaced staggered buoy, but not each short-spaced staggered buoy. Performance under the latter condition was not different from that with short-spaced gates. It is assumed here that the 80,000 dwt ship would show the same pattern of responses to the several conditions.

35. a. The need for the symmetry of gates to respond to crosscurrent is evident in CAORF Preliminary Performance Data, Volume 2, pp. 4-11, 4-13, 4-15, and 4-17.

b. Smith and Bertsche, Channel Width Principal Findings, Section 2 concludes that while both spacing and configuration influence the effect of crosscurrent, configuration has the greatest effect — with the advantage to the symmetrical gates.

36. The crosswind is not as great a problem as the crosscurrent. It becomes a problem only when there are strong and unpredictable gusts. When this is the case, good aid information is necessary to respond. Comparative wind profiles for the several experiments are given in Bertsche, Atkins, and Smith, Section 3, p. 28. The biggest changes in wind direcion are at the end of Leg 2 for the CAORF experiment and in the middle of Leg 2 for the Channel Width experiment.

a. Channel Width, Preliminary Data Analysis, pp. 2.1-11 to 2.1-14 shows the response to the crosswind with long-spaced gates or staggered buoys and no visible response with either short-spaced conditions. Given sufficient aids the pilot and/or the helmsman are able to smoothly compensate for the gusts.

b. CAORF Preliminary Data Analysis, Volume 2, pp. 4-11, 4-13, 4-15, and 4-17 shows resistance to the sudden change of wind direction for both long- and short-spaced gates and for the short-spaced staggered condition. What these conditions have in common is two buoys close to the end of the leg where the change takes place. The fourth condition, the long-spaced staggered condition differs in having only one buoy near the end of the run.. This relationship among the conditon is reinterpreted here as supporting a recommendation for short-spacing that will ensure nearby buoys, if there are such sudden changes in wind direction - and by extension, velocity.

37. a. The only traffic that appeared in the project was in the CAORF experiment. There, the traffic ship was highly predictable and was passed with a following wind and current for ownship. It was an extremely easy task that did not reveal differences among aid conditions. Therefore, it has little generality and offers little guidance here.

b. An alternative source of information on the aids needed for changing tracks under a variety of conditions is the data summarizing the Channel Width experiment that appears in Tables 2A and B in Section 1 of the present report. The third row labeled "Maneuvering without Perturbation" is analogous to finding a new track around traffic. The data here shows roughly equivalent performances for 3 conditions: long and short-spaced gates and short-spaced staggered buoys

38. The general principle that wider channels can be marked with longer spacing is supported by Smith and Bertsche, Channel Width Principal Findings, Section 4 that shows adequate performance in 800-foot channels with both staggered and gated configurations with long spacing.

39. There were no conditions involving larger ships in wider channels. The recommendation to increase the spacing of gated configurations is supported by the following related conditions:

a. Bertsche, Atkins, and Smith, Ship Variables, Section 4, p. 42, shows the larger ship has a tendency to approach each staggered buoy. Gates should eliminate this tendency in any width channel.

b. The same figure also shows that the short-spaced gates tempt the larger ship to a variety of tracks. This variety suggests such an arrangement provides a relatively high level of information for the 500-foot channel. It follows that the information would be lowered for an 800-foot channel by increasing the spacing between the gates.

c. The conclusion in the Smith and Bertsche, Channel Width Principal Findings Report, Secton 4 that the increase in distribution of tracks in the wider channel with 30,000 dwt ship and long-spaced configurations is proportionally smaller than the increase in the space available is here generalized to the 80,000 dwt ship. This is a generalizaton that should be tested.

40. Smith and Bertsche, Channel Width, Section 4 reports adequate performance in an 800 foot channel with crosscurrent with both long-spaced staggered or gated configurations. However, in the long-spaced staggered scenario in that experiment, the critical first buoy beyond the pullout was on the downcurrent side when needed. When the current changed, this would no longer be the case. This scenario cannot be interpreted as a general case. The intention here is to exclude long-spaced staggered buoys from crosscurrent situations. Marino, Smith, and Bertsche, One-Side Channel Marking, reported one-side channel marking adequate when the buoys were on the down-current side. With long-spaced staggered buoys, there is a danger that there will not be the one needed buoy on the down-current side. Possibly, there is a relationship between channel width, spacing along the down-current side, and magnitude of crosscurrent, such that some staggered configurations are adequate. Without this information, only short-spaced staggered configurations will be considered adequate. The assumption here is that long-spaced staggered buoys are used one at a time, while gated buoys are used in pairs. (See Section 2 of the Channel Width report.) This means that long-spaced gates are adequate even with the crosscurrent. The pilot will concentrate on maneuvering the ship through the center of the gate ahead, rather than on one buoy on the downcurrent side.

41. Smith and Bertsche, Channel Width, Section 4, p. 54 shows Leg 2 performance for the gated condition. There is a widening of the distribution between the gates that does not appear in the staggered condition. This might suggest that this gated configuration is inadequate for wind conditions. For a further look at the effect of this wind, the two right-hand track scenarios illustrated in Section 5, p. 62 of that report are available. In those there is no visibile effect of the crosswind. It is concluded that this wind is not enough of a problem in the 800-foot channel to require additional buoyage.

42. a. If the pilot keeps the ship on a right-hand track and does not maneuver for traffic; long-spaced configurations whether, gated or staggered, are adequate. This conclusion is supported by Smith and Bertsche, Channel Width, Section 5 which reports on transits of 800-foot channels on a right-hand track. Performance was very controlled with either long-spaced staggered or gated configurations. Of course, there was no traffic in that experiment.

b. That long-spacing is adequate for traffic in 800-foot wide channels is a necessary conclusion of this project which

includes Cooper, Cook, and Marino At-sea Data Collecton in the Baltimore Harbor approach. The Craighill Channel on which data was collected is 800 feet wide with gates approximately 1-1/2 nm apart and traffic is quite frequent there.

c. The question remains as to whether long-spaced staggered buoys are adequate for traffic in wide channels. Assume first that what is critical is an outline of the edge of the channel, if the ship approaches it. For such an outline it is irrelevant whether the buoys are staggered or gated. (See Explanatory Note 41a.) Assume also that the principal value of gates is for finding a precise crosstrack position in the channel. If, in the wider channel, crosstrack position that does not encroach on the channel edge is not critical, staggered buoys should be adequate for traffic. This is a reasonable conclusion given the data available at this time.

43. The recommendations here assume only visual information. This detection distance is marginal for visual piloting. It is possible that given the alternative, pilots would make some use of radar. Whether this would improve performance is problematic.

a. Cooper, Marino, and Bertsche, Radio Aids I evaluated a variety of displays, the closest to radar of which is the graphic display with heading vector. Performance for the condition, illustrated on page 50 of that report, shows a poor turn pullout, leading to an adequate recovery. Generalizing from this, radar would not be a help in the turn; but would help the pilots to bridge any visual gaps that occur late in recovery or during trackkeeping.

b. There is no reason to expect radar to be a help when spacing and detection distance do not produce gaps. Smith and Bertsche, CAORF Principal Findings, Section 3.3 concluded that short detection distance is not a problem when there are not gaps. If one buoy or pair of buoys can be seen, more do not improve performance. This conclusion is further supported in Marino, Smith, and Bertsche, One-side Channel Marking Principal Findings, Section 5.

44. All long-spaced gated configurations have been replaced by short-spaced gates. Smith and Bertsche, CAORF Principal Findings, Section 3.3 describes the consequences of long-spaced gates with 3/4 nm detection distance resulting in a 3-minute gap when the pilot saw nothing. In Leg 2 with the crosscurrent, resulting crosstrack standard deviation was one of the largest in the project. Such gaps should be avoided for visual piloting that involves recovery and/or maneuvering.

45. All short-spaced staggered configurations have been retained. Marino, Smith, and Bertsche, One-Side Channel Marking Principal Findings, Section 3 reports adequate performance with short-spaced staggered buoys and 3/4 nm detection distance.

46. All long-spaced staggered configurations have been retained. Smith and Bertsche, CAORF Principal Findings, Section 3.3, p. 78 shows little difference between long- and short-spaced staggered configurations at 3/4 nm detection distance.

47. No runs are available with 800-foot channels and 3/4 nm detection distance. The recommendations for the 800-foot channels have been adjusted for 3/4 nm visibility by the same logic as for the 500-foot channels that is described in Explanatory notes 43 to 46.

48. Smith and Bertsche, Channel Width Principal Findings, Section 5 supports this conclusion.

49. Night has its principal effect in the turn and pullout and seems to have a minimal effect in the recovery and trackkeeping regions. The only comparisons that evaluated day/night differences is in Smith and Bertsche, CAORF Principal Findings Report, Section 3.4. Because of the fractional design used in that expeimrent, the effects are not clear. Another source of data is CAORF Preliminary Data Analysis, Volume 2, p 3-8 which shows the day/night main effect: there seems to be a difference in the turn only. CAORF Preliminary Data Analysis, Vol. 5, p. 2-1 to 2-25 shows an interaction of related conditions with day/night. If the turns - where day/night is confounded with number of turn buoys is ignored - there is little difference remaining in the straightaway. This effect (or lack of one) is sufficiently important to deserve replication in a later experiment.

50. a. All the buoy experiments that showed trackkeeping in Leg 1 with following wind and current showed adequate behavior with any gated or staggered configuration. These experiments include:
   Smith and Bertsche, CAORF
   Smith and Bertsche, Channel Width
   Bertsche, Atkins, and Smith, Ship Variables

   The additional buoy experiment; Marino, Smith, and Bertsche, One-Side Channel Markings; cannot be considered support for adequate trackkeeping with one-side channel marking because the short Leg 1 trackkeeping portion was done with the opposite-side turn buoy in view.

   b. Trackkeeping performance late in Leg 2, where the current is minimal and the wind gusts are not a problem, can be examined as well.

   - Long-spaced staggered buoys are in Bertsche, Atkins, and Smith, Ship Variables, Appendix E, Scenario 2.

   - Long-spaced gated buoys are in Marino, Smith and Bertsche, Section 2, Scenario 1, page 19.

   Both conditions show adequate performance.

51. Bertsche, Atkins, and Smith, Ship Variables Principal Findings Report, Section 4, page 42 shows the 80,000 dwt ship at 6 knots in Leg 2 with long-spaced staggered buoys. Trackkeeping late in the leg is adequate, even though there is some crosswind and crosscurrent. If this low buoy density condition is adequate, the other should be, too.

52. The wind profiles for the several experiments are compared in Bertsche, Atkins, and Smith, Ship Variables Principal Findings, Section 3. The worse wind conditions in the project were in the middle of Leg 2 for the Channel Width experiment and at the end of Leg 2 for the CAORF experiment. In the Channel Width experiment, the extreme wind comes while the ship and pilot are still recovering. In the long-spaced conditions, the resulting perturbation is visible in performance, as illustrated in the Preliminary Data Analysis for that experiment. In the CAORF experiment the wind perturbation comes at the end of the leg, where the ship and pilot are trackkeeping. While performance in the long-spaced staggered scenario -- illustrated in CAORF Preliminary Data Analysis, Volume 2, page 4-13 -- is the poorest among the alternatives, it is still adequate. It seems the pilot and/or helmsman is better able to cope with the sudden wind if he/they no longer must concern himself/themselves with maneuvering to the centerline or compensating for the current.

53. See Explanatory Note 49 for a discussion of day/night beyond the turn pullout.

54. If the minimum configuration is adequate for 500-foot wide channels, it is adequate for 800-foot wide channels. But such conditions are available in the project. Smith and Bertsche, Channel Width Principal Findings, Section 4 reports adequate performance in all parts of the scenario with the wider channel and long spacing.

55. For the recovery region -- see Explanatory Note 43 -- it was recommended that gates always be spaced shorter than the detection distance. This is not necessary for trackkeeping, at least for the dimensions involved here. In CAORF Preliminary Performance Data, Volume 1, page 4-16 there is performance in Leg 1 with the following wind and current, short detection distance, and long spacing. There, the 3-minute gap in which nothing is visible that caused a problem in Leg 2 has no effect.

56. See Explanatory Note A-12.

57. See Explanatory Note A-13.

58. In the project only a few conditions were run with 800-foot wide channels. They are described in Smith and Bertsche, Channel Width Principal Findings, Sections 4 and 5. In that experiment the 800-foot channels were combined with 35-degree noncutoff turns marked with three buoys. There were no lower angle turns or turns marked with fewer buoys. Because no such evaluations were done,

there were no modifications of the recommendations for turn marking for the wider channel. As a result, the recommended markings are conservative, as the example demonstrates.

59. United States - East Coast, Maryland, Chesapeake Bay, Approaches to Baltimore, NOAA, Number 12278, October 11, 1980.

60. Nothing like this was evaluated in the project. It is probably too specialized a geography to include in a program of generic research, but appropriate for an implementation or port design study.

APPENDIX C

CALCULATION OF THE RELATIVE RISK FACTOR FOR AN SYSTEM DESIGN

C.1 INTRODUCTION

The relative risk factors (RRF) for a particular channel are calculated separately for turn regions, recovery regions, and trackkeeping regions. Appendix A provides instructions for the identification of these regions.

The determination of the RRF is limited to AN configurations which meet the adequate AN requirements as determined in Appendix B. Data are not provided for determining RRF for nonstandard configurations.

These data must not be used to justify designs which are less than adequate for the conditions as derived in Appendix B.

The calculation of the RRF begins with the selection of baseline values for the mean crosstrack displacement (MN) and the crosstrack standard deviation (SD) for each region. These values are selected from tables and are dependent on the AN configuration and the environmental conditions. The baseline values of MN and SD are adjusted for the ship size, expected ship speed, and channel width of the candidate channel. The adjusted values, MN' and SD', are used together with the ship and channel dimensions to calculate the probabilities of the ship's hull crossing either edge of the channel. The relative risk factor is calculated as the sum of these probabilities.

The adjusted mean and standard deviations are calculated as the product of the baseline values times correction factors associated with ship's size, ship's speed and channel width. Equations C-1 and C-2 indicate the calculations which must be made for each region:

$$MN' = (MN)(MCSHP)(MCSPD)(MCWID) \tag{C-1}$$

$$SD' = (SD)(SCSHP)(SCSPD)(SCWID) \tag{C-2}$$

where:

MN: Baseline mean crosstrack position (feet)
SD: Baseline crosstrack standard deviation (feet)
MCSHP: Mean correction factor for ship size
MCSPD: Mean correction factor for ship speed
MCWID: Mean correction factor for channel width
SCSHP: Standard deviation correction factor for ship size
SCSPD: Standard deviation correction factor for ship speed
SCWID: Standard deviation correction factor for channel width

The probabilities of the ship's hull crossing the channel edges are calculated based on the number of adjusted standard deviations which fall between the ship's extreme points and the channel edges. Equations

C-3, C-4, and C-5 indicate the calculations required to determine these multiples:

$$B' = (L/2)(VX/VMIN) + (B/2) \qquad (C\text{-}3)$$

$$NS = [(W/2) - (MN') - (B')]/(SD') \qquad (C\text{-}4)$$

$$NP = [(W/2) + (MN') - (B')]/(SD') \qquad (C\text{-}5)$$

where:

B':	Ship's beam adjusted for drift angle (feet)
L:	Ship's length (feet)
VX:	Cross channel component of current (knots)
VMIN:	Ship's minimum transit speed (knots)
B:	Ship's beam (feet)

and

NS:	Number of SD' between the extreme starboard point of the ship's hull and the starboard channel edge (may be negative)
NP:	Number of SD' between the extreme port point of the ship's hull and the port channel edge (may be negative)
W:	Channel width (feet)

The probabilities of crossing the port and starboard edges of the channel are calculated as indicated in equations C-6 and C-7. These equations may be solved using either an interactive integration technique on a digital computer or utilizing the data provided in Table C-1. The relative risk factor is calculated as the sum of the probabilites (equation C-8).

$$PS = 0.5 - (NS/\ NS\ )\int_0^{|NS|}(1/\ 2)\ e^{-(1/2)t^2}\ dt \qquad (C\text{-}6)$$

$$PP = 0.5 - (NP/\ NP\ )\int_0^{|NP|}(1/\ 2)\ e^{-(1/2)t^2}\ dt \qquad (C\text{-}7)$$

$$RRF = PS + PP \qquad (C\text{-}8)$$

where:

PS:	Probability of the extreme starboard point of the ship's hull crossing the starboard channel edge. Assumes a normal distribution of the tracks.
PP:	Probability of the extreme port point of the ship's hull crossing the port channel edge. Assumes a normal distribution of tracks.

TABLE C-1. NORMAL DISTRIBUTION VALUES FOR THE CUMULATIVE PROBABILITIES PS OR PP, OF A POINT FALLING BEYOND NS OR NP (SEE NOTE A)

N	P(N)	N	P(N)	N	P(N)	N	P(N)
.00	.5000	.50	.3085	1.00	.1587	1.50	.0668
.01	.4960	.51	.3050	1.01	.1562	1.51	.0655
.02	.4920	.52	.3015	1.02	.1539	1.52	.0643
.03	.4880	.53	.2981	1.03	.1515	1.53	.0630
.04	.4840	.54	.2946	1.04	.1492	1.54	.0618
.05	.4801	.55	.2912	1.05	.1469	1.55	.0606
.06	.4761	.56	.2877	1.06	.1446	1.56	.0594
.07	.4721	.57	.2843	1.07	.1423	1.57	.0582
.08	.4681	.58	.2810	1.08	.1401	1.58	.0571
.09	.4641	.59	.2776	1.09	.1379	1.59	.0559
.10	.4602	.60	.2743	1.10	.1357	1.60	.0548
.11	.4562	.61	.2709	1.11	.1335	1.61	.0537
.12	.4522	.62	.2676	1.12	.1314	1.62	.0526
.13	.4483	.63	.2643	1.13	.1292	1.63	.0516
.14	.4443	.64	.2611	1.14	.1271	1.64	.0505
.15	.4404	.65	.2578	1.15	.1251	1.65	.0495
.16	.4364	.66	.2546	1.16	.1230	1.66	.0485
.17	.4325	.67	.2514	1.17	.1210	1.67	.0475
.18	.4286	.68	.2483	1.18	.1190	1.68	.0465
.19	.4247	.69	.2451	1.19	.1170	1.69	.0455
.20	.4207	.70	.2420	1.20	.1151	1.70	.0446
.21	.4168	.71	.2389	1.21	.1131	1.71	.0436
.22	.4129	.72	.2358	1.22	.1112	1.72	.0427
.23	.4090	.73	.2327	1.23	.1093	1.73	.0418
.24	.4052	.74	.2296	1.24	.1075	1.74	.0409
.25	.4013	.75	.2266	1.25	.1056	1.75	.0401
.26	.3974	.76	.2236	1.26	.1038	1.76	.0392
.27	.3936	.77	.2206	1.27	.1020	1.77	.0384
.28	.3897	.78	.2177	1.28	.1003	1.78	.0375
.29	.3859	.79	.2148	1.29	.0985	1.79	.0367
.30	.3821	.80	.2119	1.30	.0968	1.80	.0359
.31	.3783	.81	.2090	1.31	.0951	1.81	.0351
.32	.3745	.82	.2061	1.32	.0934	1.82	.0344
.33	.3707	.83	.2033	1.33	.0918	1.83	.0336
.34	.3669	.84	.2005	1.34	.0901	1.84	.0329
.35	.3632	.85	.1977	1.35	.0885	1.85	.0322
.36	.3594	.86	.1949	1.36	.0869	1.86	.0314
.37	.3557	.87	.1922	1.37	.0853	1.87	.0307
.38	.3520	.88	.1894	1.38	.0838	1.88	.0301
.39	.3483	.89	.1867	1.39	.0823	1.89	.0294
.40	.3446	.90	.1841	1.40	.0808	1.90	.0287
.41	.3409	.91	.1814	1.41	.0793	1.91	.0281
.42	.3372	.92	.1788	1.42	.0778	1.92	.0274
.43	.3336	.93	.1762	1.43	.0764	1.93	.0268
.44	.3300	.94	.1736	1.44	.0749	1.94	.0262
.45	.3264	.95	.1711	1.45	.0735	1.95	.0256
.46	.3228	.96	.1685	1.46	.0721	1.96	.0250
.47	.3192	.97	.1660	1.47	.0708	1.97	.0244
.48	.3156	.98	.1635	1.48	.0694	1.98	.0239
.49	.3121	.99	.1611	1.49	.0681	1.99	.0233
.50	.3085	1.00	.1587	1.50	.0668	2.00	.0228

NOTE A: IF N IS NEGATIVE P(−N) = 1 − P(N)

TABLE C-1. NORMAL DISTRIBUTION VALUES FOR THE CUMULATIVE PROBABILITIES PS OR PP, OF A POINT FALLING BEYOND NS OR NP (SEE NOTE A) (CONTINUED)

N	P(N)	N	P(N)	N	P(N)	N	P(N)
2.00	.0227	2.50	.0062	3.00	.0013	3.50	.0002
2.01	.0222	2.51	.0060	3.01	.0013	3.51	.0002
2.02	.0217	2.52	.0059	3.02	.0013	3.52	.0002
2.03	.0212	2.53	.0057	3.03	.0012	3.53	.0002
2.04	.0207	2.54	.0055	3.04	.0012	3.54	.0002
2.05	.0202	2.55	.0054	3.05	.0011	3.55	.0002
2.06	.0197	2.56	.0052	3.06	.0011	3.56	.0002
2.07	.0192	2.57	.0051	3.07	.0011	3.57	.0002
2.08	.0188	2.58	.0049	3.08	.0010	3.58	.0002
2.09	.0183	2.59	.0048	3.09	.0010	3.59	.0002
2.10	.0179	2.60	.0047	3.10	.0010	3.60	.0002
2.11	.0174	2.61	.0045	3.11	.0009	3.61	.0002
2.12	.0170	2.62	.0044	3.12	.0009	3.62	.0001
2.13	.0166	2.63	.0043	3.13	.0009	3.63	.0001
2.14	.0162	2.64	.0041	3.14	.0008	3.64	.0001
2.15	.0158	2.65	.0040	3.15	.0008	3.65	.0001
2.16	.0154	2.66	.0039	3.16	.0008	3.66	.0001
2.17	.0150	2.67	.0038	3.17	.0008	3.67	.0001
2.18	.0146	2.68	.0037	3.18	.0007	3.68	.0001
2.19	.0143	2.69	.0036	3.19	.0007	3.69	.0001
2.20	.0139	2.70	.0035	3.20	.0007	3.70	.0001
2.21	.0136	2.71	.0034	3.21	.0007	3.71	.0001
2.22	.0132	2.72	.0033	3.22	.0006	3.72	.0001
2.23	.0129	2.73	.0032	3.23	.0006	3.73	.0001
2.24	.0125	2.74	.0031	3.24	.0006	3.74	.0001
2.25	.0122	2.75	.0030	3.25	.0006	3.75	.0001
2.26	.0119	2.76	.0029	3.26	.0006	3.76	.0001
2.27	.0116	2.77	.0028	3.27	.0005	3.77	.0001
2.28	.0113	2.78	.0027	3.28	.0005	3.78	.0001
2.29	.0110	2.79	.0026	3.29	.0005	3.79	.0001
2.30	.0107	2.80	.0026	3.30	.0005	3.80	.0001
2.31	.0104	2.81	.0025	3.31	.0005	3.81	.0001
2.32	.0102	2.82	.0024	3.32	.0005	3.82	.0001
2.33	.0099	2.83	.0023	3.33	.0004	3.83	.0001
2.34	.0096	2.84	.0023	3.34	.0004	3.84	.0001
2.35	.0094	2.85	.0022	3.35	.0004	3.85	.0001
2.36	.0091	2.86	.0021	3.36	.0004	3.86	.0001
2.37	.0089	2.87	.0021	3.37	.0004	3.87	.0001
2.38	.0087	2.88	.0020	3.38	.0004	3.88	.0001
2.39	.0084	2.89	.0019	3.39	.0003	3.89	.0000
2.40	.0082	2.90	.0019	3.40	.0003	3.90	.0000
2.41	.0080	2.91	.0018	3.41	.0003	3.91	.0000
2.42	.0078	2.92	.0018	3.42	.0003	3.92	.0000
2.43	.0075	2.93	.0017	3.43	.0003	3.93	.0000
2.44	.0073	2.94	.0016	3.44	.0003	3.94	.0000
2.45	.0071	2.95	.0016	3.45	.0003	3.95	.0000
2.46	.0069	2.96	.0015	3.46	.0003	3.96	.0000
2.47	.0068	2.97	.0015	3.47	.0003	3.97	.0000
2.48	.0066	2.98	.0014	3.48	.0003	3.98	.0000
2.49	.0064	2.99	.0014	3.49	.0002	3.99	.0000
2.50	.0062	3.00	.0013	3.50	.0002	4.00	.0000

NOTE A: IF N IS NEGATIVE P(−N) = 1 − P(N)

RRF: Relative risk factor

Data and detailed instructions for the calculation of RRF are provided in Sections C.2 through C.5 of this appendix. The application of each section is as follows:

- Section C.2: Calculation of RRF for Turn Regions
- Section C.3: Calculation of RRF for Recovery Regions
- Section C.4: Calculation of RRF for Trackkeeping Regions

There may exist special design problems for which the data in sections C.2, C.3 and C.4 are inadequate for determining values for the adjusted means (MN' and SD'). This may occur because of unique channel geometries, unique environmental conditions (especially currents), considerations of high risk cargos or incompleteness of existing data bases. For these applications the specific channel system and ships may be evaluated directly on the simulator to find exact values for MN' and SD'. Section C.5 describes this procedure.

C.2 CALCULATION OF RRF FOR TURN REGIONS

This section provides instructions and the data required to calculate the relative risk factor for turns. The calculation is conducted on a tabulation Form XXX provided as Figure C-1. The numbered instructions correspond to their identical numbered boxes on Form XXX. The piloting performance data and correction factors are provided in Tables C-2 through C-7. In these tables the notations D1, D2, etc., refer to explanatory notes on pages C-51 through C-62.

Instructions

1. Enter a written description of the turn and the waterway or port name.

2. Enter the NOAA chart number which provides a detailed diagram of the existing AN configuration and present bathometry (depth) and dimensions (width and turn angle).

3. Enter the latitude and longitude of the turn apex midway between the channel edges.

4. Enter the channel width (feet) as indicated on the chart (or) the width of navigable water with regard to the maximum draft of the user vessels.

5. Enter the maximum current component which flows perpendicular to the channel edges on either side of the turn. Enter as a positive value regardless of direction. If none expected, enter 0.5 knots to account for ship lateral drift during the turning maneuver.

6. Enter the maximum wind velocity (knots) which may occur during normal port operations. Enter as a positive value regardless of direction.

FORM XXX

CALCULATION OF RRF: TURN REGION

TURN IDENTIFICATION

1. TURN NAME AND LOCATION	2. CHART NO.
3 LATITUDE AND LONGITUDE OF TURN APEX	

CHANNEL AND ENVIRONMENTAL PARAMETERS

4 ENTER CHANNEL WIDTH (FEET)	W= FT
5 ENTER MAXIMUM CROSS CURRENT COMPONENT (KNOTS)	VX= KTS
6 ENTER MAXIMUM WIND VELOCITY (KNOTS)	VW= KTS

DESIGN VESSEL PARAMETERS

7. ENTER SHIP TYPE AND DWT	
8. ENTER MINIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMIN= KTS
9. ENTER MAXIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMAX= KTS
10. ENTER SHIPS LENGTH (FEET)	L= FT
11. ENTER SHIPS BEAM (FEET)	B= FT

SRA DESIGN PARAMETERS (CIRCLE ONE)

12. AN DETECTION DISTANCE	LESS THAN 1 NM (RADAR)	GREATER THAN 1 NM (VISUAL)	
13. DAYLIGHT CONDITIONS	DAY	NIGHT, DUSK OR DAWN	
14. TURN CONFIGURATIONS	NONCUTOFF	CUTOFF	
15. SRA CONFIGURATIONS	3 BUOYS HI SENS RNG.	2 BUOYS LO SENS RNG.	1 BUOY
16. TURN ANGLE	0 TO 20°	20 TO 40°	GREATER THAN 40 DEG.

RADIO AID DESIGN PARAMETERS (CIRCLE ONE)

17. GYRO AIDING	YES	NO	
18. RMS NOISE AT SITE	0 TO 6 M	6 TO 18 M	18 TO 30 M
19. DISPLAY FORMAT	GRAPHIC:W/PREDICTOR / PERSPECTIVE	GRAPHIC:W/VECTOR / DIGITAL:W/DISTANCE	DIGITAL:W/TURNING
20. THROUGH SYSTEM RISE TIME	3 SEC.	12 SEC.	24 SEC.

CALCULATE ADJUSTED MN AND SD

21A ENTER BASELINE MEAN TABLE C.2,C.3,C.4	22A ENTER MEAN SHIP CORRECTION FACTOR TABLE C.5	23A ENTER MEAN SPEED CORRECTION FACTOR TABLE C.6	24A ENTER MEAN WIDTH CORRECTION FACTOR TABLE ___		25 CALCULATE ADJUSTED MEAN
MN	MCSHP	MCSPO	MCWID		MN'
(FT)x(	)x(	)x(	)	=	(FT)

21B ENTER BASELINE STD. DEV. 1 TABLE C.2,C.3,C.4	22B ENTER S.D. SHIP CORRECTION FACTOR TABLE C.5	23 B ENTER S.D. SPEED CORRECTION FACTOR TABLE C.6	24B ENTER S.D. WIDTH CORRECTION FACTOR TABLE C.7		26 CALCULATE ADJUSTED STD. DEV.
SD	SCSHP	SCSPD	SCWID		SD'
(FT)x(	)x(	)x(	)	=	(FT)

CALCULATE ADJUSTED BEAM

27 ENTER SHIP LENGTH LINE 10	28 ENTER CROSS TRACK CURRENT VELOCITY LINE 5	29 ENTER MINIMUM EXPECTED SPEED LINE 8		30 ENTER SHIPS BEAM LINE 11		31 CALCULATE ADJUSTED BEAM
L	VX	VMIN		B		B'
(/2)x(	/	)	+	(/2)	=	(FT)

CALCULATE THE RELATIVE RISK FACTOR

32A ENTER CHAN. WIDTH LINE 4	33A ENTER ADJUSTED MEAN LINE 25	34A ENTER ADJUSTED BEAM LINE 31		35A ENTER ADJUSTED STD. DEV. LINE 26		36 CALCULATE STD. MULTIPLE TO STARBOARD
W	MN'	B'		SD'		NS
(/2)-(	)-(	)	/	( )	=	( )

32B ENTER CHAN. WIDTH LINE 4	33B ENTER ADJUSTED MEAN LINE 25	34B ENTER CHAN. ADJUSTED BEAM LINE 31		35B ENTER ADJUSTED STD. DEV. LINE 26		37 CALCULATE S.D. STD. MULTIPLE TO PORT
W	MN'	B'		SD'		NP
(/2)+(	)-(	)	/	( )	=	( )

38 DETERMINE PROB. OF CROSSING NS TABLE C.1	39 DETERMINE PROB. OF CROSSING NP TABLE C.1		40 CALCULATE RELATIVE RISK FACTOR
PS	PP		RRF
( )+(	)	=	( )

Figure C-1. Calculation of Relative Risk Factor for Turn Regions, Data Form XXX

TABLE C-2. BASELINE VALUES FOR MN AND SD, TURN REGION, VISUAL PILOTING

LINE 12: AN DETECTION DISTANCE	LINE 13: DAYLIGHT CONDITION	LINE 14: TURN CONFIGURATION	LINE 15: AN CONFIGURATION	LINE: 16 TURN ANGLE: 0 TO 20 DEG (MN : SD)	20 TO 30 DEG. (MN : SD)	30 TO 40 DEG. (MN : SD)
GREATER THAN 1NM (VISUAL PILOTING)	DAY	NON CUTOFF	3 BUOYS	22 : 50 (D1)	41 : 43 (D2)	59 : 35 (D3)
			2 BUOYS	DATA NOT YET AVAILABLE	DATA NOT YET AVAILABLE	94 : 38 (D5)
			1 BUOY	40 : 53 (D6)	82 : 75 (D2)	123 : 96 (D7)
			HI SENS RNG	22 : 94 (D8)	77 : 132 (D2)	132 : 170 (D9)
			LO SENS RNG	35 : 139 (D10)	121 : 196 (D2)	207 : 251 (D11)
		CUTOFF	3 BUOYS	81 : 52 (D12)	77 : 56 (D2)	73 : 60 (D13)
			2 BUOYS	DATA NOT YET AVAILABLE	DATA NOT YET AVAILABLE	DATA NOT YET AVAILABLE
			1 BUOY	INADEQUATE	INADEQUATE	INADEQUATE
			HI SENS RNG	22 : 94 (D14)	77 : 132 (D2)	132 : 170 (D15)
			LO SENS RNG	35 : 139 (D16)	121 : 196 (D2)	207 : 251 (D17)
	NIGHT,DUSK,DAWN	NON CUTOFF	3 BUOYS	27 : 63 (D18)	40 : 76 (D2)	52 : 89 (D19)
			2 BUOYS	DATA NOT YET AVAILABLE	DATA NOT YET AVAILABLE	DATA NOT YET AVAILABLE
			1 BUOY	9 : 106 (D22)	112 : 131 (D2)	215 : 153 (D23)
			HI SENS RNG	22 : 94 (D24)	77 : 132 (D2)	132 : 170 (D25)
			LO SENS RNG	35 : 139 (D26)	121 : 196 (D2)	207 : 251 (D27)
		CUTOFF	3 BUOYS	46 : 77 (D28)	44 : 75 (D2)	42 : 73 (D29)
			2 BUOYS	DATA NOT YET AVAILABLE	DATA NOT YET AVAILABLE	DATA NOT YET AVAILABLE
			1 BUOY	INADEQUATE	INADEQUATE	INADEQUATE
			HI SENS RNG	22 : 94 (D30)	77 : 132 (D2)	132 : 170 (D31)
			LO SENS RNG	35 : 139 (D32)	121 : 196 (D2)	207 : 251 (D33)

DATA FROM EXPERIMENT   INTERPOLATED VALUES

TABLE C-3. BASELINE VALUES FOR MN AND SD, TURN REGIONS, RADAR PILOTING

LINE 12: AN DETECTION DISTANCE	LINE 13: DAYLIGHT CONDITION	LINE 14: TURN CONFIGURATION	LINE 15: AN CONFIGURATION	LINE: 16 TURN ANGLE 0 TO 20 DEG. MN : SD	20 TO 30 DEG. MN : SD	30 TO 40 DEG. MN : SD
LESS THAN 1 NM (RADAR PILOTING)	DAY,NIGHT,DUSK,DAWN	NON CUTOFF	3 BUOYS			
			2 BUOYS			
			1 BUOY			
			RACON LEAD MRK			
			RACON RANGE			
					DATA NOT YET AVAILABLE	
		CUTOFF	3 BUOYS			
			2 BUOYS			
			1 BUOY			
			RACON LEAD MRK			
			RACON RANGE			

TABLE C-4. BASELINE VALUES FOR MN AND SD, TURN REGIONS, RADIO AID PILOTING

LINE 16: TURN ANGLE

LINE 17	LINE 18	LINE 19	LINE 20	0 TO 20 DEG MN : SD	20 TO 30 DEG MN : SD	30 TO 40 DEG MN : SD
PERFECT POSITION & VELOCITY DATA AVAILABLE		LINE 19: DISPLAY FORMAT: GRAPHIC W/ VECTOR				142 : 117 (D34)
		GRAPHIC W/ PREDICT				87 : 77 (D35)
		PERSPECTIVE				91 : 111 (D36)
		DIGITAL/DISTANCE				4 : 288 (D37)
		DIGITAL/TURNING				53 : 107 (D38)
NO GYRO AIDING IN TRACKER	LINE 18: RMS NOISE AT SITE: 0 TO 6 M	LINE 19: DISPLAY FORMAT: GRAPHIC W/HDG VECTOR	LINE 20: SYSTEM RISE TIME: 3 SEC			169 : 65 (D39)
			12 SEC			NOTE A
			24 SEC			NOTE A
	6 TO 18 M		3 SEC			78 : 67 (D40)
			12 SEC			60 : 70 (D41)
			24 SEC			51 : 51 (D42)
	18 TO 36 M		3 SEC			79 : 66 (D43)
			12 SEC			83 : 70 (D44)
			24 SEC			61 : 76 (D45)
LINE 17: GYRO AIDING: YES, GYRO AIDING IN TRACKER	LINE 18: RMS NOISE AT SITE: 0 TO 6 M	LINE 19: DISPLAY FORMAT: GRAPHIC W/HDG VECTOR	LINE 20: SYSTEM RISE TIME: 3 SEC			NOTE B
			12 SEC			NOTE B
			24 SEC			169 : 65 (D39)
	6 TO 18 M		3 SEC			NOTE B
			12 SEC			NOTE B
			24 SEC			95 : 104 (D46)
	18 TO 36 M		3 SEC			NOTE B
			12 SEC			NOTE B
			24 SEC			75 : 73 (D47)

DESIGN FOR WORST PRACTICAL CASE, i.e. 30 TO 40 DEG. TURNS

USE SIMULATOR TO EVALUATE SMALLER TURN ANGLES FOR LIMITED APPLICATIONS

DATA FROM EXPERIMENT   INTERPOLATED VALUES

NOTE A. LONG RISE TIMES INTRODUCE LAG ERRORS OF MAGNITUDE GREATER THAN THOSE INTRODUCED BY THE RMS NOISE. RA-1

NOTE B. 24 SEC RISE TIME APPEARS TO BE NEAR OPTIMUM WITH GYRO AIDING. SHORTER RISE TIMES INTRODUCE ERRORS. RA-2

TABLE C-5. SHIP SIZE CORRECTION FACTORS FOR TURN REGIONS

FROM LINE 7: SHIP TYPE AND DWT:	MEAN: SHIP CORRECTION FACTOR MCSHP	STANDARD DEVIATION: CORRECTION FACTOR SCSHP
TANKER, 30,000 DWT	1.0	1.0
TANKER, 80,000 DWT	2.8	1.0
TANKER, 120,000 DWT	DATA NOT YET AVAILABLE	DATA NOT YET AVAILABLE
TANKER, 250,000 DWT		
CONTAINER,		
CONTAINER,		
LNG, 124,000 FT^3		

TABLE C-6. SHIP SPEED CORRECTION FACTORS FOR TURN REGIONS

			MEAN AND STANDARD DEVIATION SHIP SPEED CORRECTION FACTORS	
			MCSPD	SCSPD
		LINE 7: SHIP TYPE AND DWT		
LINE 9: MAXIMUM EXPECTED SPEED VMAX	4 TO 8 KNOTS	TANKER 30,000 DWT	1.0	1.0
		TANKER 80,000 DWT	1.0	1.0
		TANKER 120.000 DWT	DATA NOT YET AVAILABLE	
		TANKER 250,000 DWT		
		CONTAINER		
		CONTAINER		
		L.N.G.		
	8 TO 12 KNOTS	TANKER 30,000 DWT	1.0	1.0
		TANKER 80,000 DWT	1.0	1.5
		TANKER 120,000 DWT	DATA NOT YET AVAILABLE	
		CONTAINER		
		CONTAINER		
		L.N.G		

TABLE C-7. CHANNEL WIDTH CORRECTION FACTORS FOR TURN REGIONS

FROM LINE 4: CHANNEL WIDTH: W

$\boxed{W < 500 \text{ FEET*}}$

MCWID = SCWID = 1.0

$\boxed{500 < W < 800 \text{ FEET}}$

MCWID = SCWID = 1 + (.5)(W-500)/(300)

*THE FACTOR 1.0 IS SELECTED AS CONSERVATIVE SINCE EXPERIMENTAL DATA ARE NOT YET AVAILABLE FOR CHANNELS LESS THAN 500 FEET.

7. Enter the ship type and deadweight tonnage of the least maneuverable vessel expected to utilize the waterway. This will normally be the ship with the largest dwt. Tug and tow and push barges are not presently considered for design purposes.

8. Enter the minimum expected transit speed for the vessel noted in line 7. If unknown, enter 4.0 knots as a worst case value.

9. Enter the maximum expected transit speed for the vessel noted in line 7. This will typically be the vessel's full ahead maneuvering speed, not its full capability sea speed.

10. Enter the length (feet) of the vessel noted in line 7.

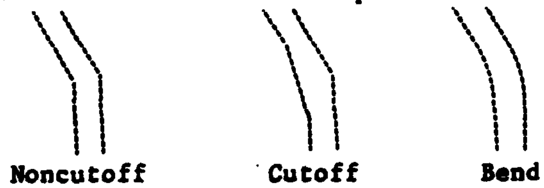
11. Enter the beam (feet) of the vessel noted in line 7.

NOTE: If visual or radar piloting techniques are to be evaluated, complete instructions 12 through 16. If radio aid piloting techniques are to be evaluated, complete instructions 17 through 20.

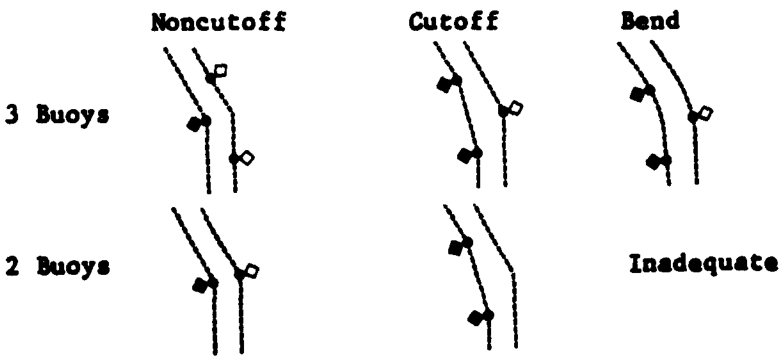
12. Circle the AN detection distance for which RRF is to be determined. The AN detection distance is taken to be the distance at which 50 percent of the pilots will see the AN. Radar piloting techniques are assumed for detection distances less than 1 nm. Visual piloting techniques are assumed for detection distances greater than 1 nm.

13. Circle the daylight conditions for which the RRF is to be determined. Night, dusk, and dawn are conservatively assumed to be the same condition.

14. Circle the turn configuration according to the dredged configuration. Bends are assumed to be equivalent to noncutoff turns.



15. Circle the AN configuration for which the RRF is to be determined. Only those configurations shown below apply. Turns with fewer AN than these indicated are considered inadequate. The configurations are shown as a function of turn configuration.



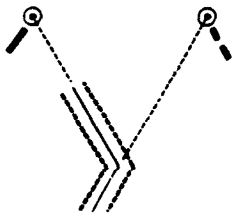
1 Buoy  Inadequate Inadequate

For turns which are marked only with range lights and no buoys exist at the turns, denote the range sensitivity as selected from the table below:

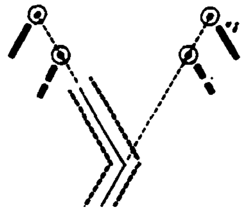
	K*	X_Q*
High sensitivity range	0.5 to 0.8	1.5 to 6 feet
Low sensitivity range	3.5 to 10.0	20 to 40 feet

*See Coast Guard Publication 39B for calculation of the values of lateral sensitivity K and crosstrack position X for the Θ_Q displacement (i.e., X_Q).

For turns which are marked only with racons and no buoys exist at the turn, denote the racon configuration as either a (single) "racon leading mark" or a (double) "racon range."



Racon Leading Marks



Racon Ranges

16. Circle the appropriate bounds for the turn angle. Large angle bends may be assumed to represent a series of cutoff turns as divided by the AN on the inside of the turn.

NOTE: If Radio Aids are not to be considered, continue with instruction 21A and 21B.

17. Circle whether or not a ship's gyro heading signal is utilized to improved tracking accuracy in turns.

18. Circle the bounds of RMS signal noise measured at the site (meters). Do not include bias errors.

19. Circle the radio aid display format to be utilized in accordance with the following minimum operating characteristics:

- Graphic with vector: PPI type display, selectable range scale (3/4 nm minimum), course and/or heading vector, ship's hull image to scale

- Graphic with predictor: PPI type display, selectable range scale (3/4 nm minimum), position predictor vector based on hydrodyamic model of the vessel, ship's hull image to scale

- Perspective: CRT type display, maximum field of view: 60 degrees, channel edges indicated as lines, ship's bow image

- Digital with distance: Digital readout of the following data: distance off centerline, crosstrack velocity, distance to waypoint

- Digital with turning: Digital readout of the following data: distance off centerline, crosstrack velocity, distance to waypoint, turn rate, recommended turn rate*

*Recommended turn rate is that turn rate which will achieve a tangential intersection between the ship's course and the centerline of the next leg given the ship's present position, course, and speed.

20. Circle the through system rise time. This is the time required for the displayed position to equal 0.667 of the value of a step change in the input signal value. The through system rise time accounts for the response of both the receiver and any additional trackers (filters) in the system.

21A and 21B. Determine the baseline values of MN and SD from Tables C-2, C-3 and C-4. Utilize Table C-2 if AN detection distance (line 12) is greater than 1 nm and visual piloting is assumed. Utilize Table C-3 if AN detection distance (line 12) is less than 1 nm and radar piloting is assumed. Utilize Table C-4 if radio aid display piloting is assumed. Enter the baseline values on lines 21A and 21B respectively. Selection of the baseline values for visual or radar navigation will be dependent on the parameters circled on lines 12 through 16. Selection of the baseline values for radio aid navigation will be dependent on the parameters circled on lines 17 through 20.

22A and 22B. Determine the ship size correction factors, MCSHP and SCSHP, from Table C-5. Enter these values on lines 22A and 22B respectively. Selection of the correction factors will be dependent on the ship size noted on line 7.

23A and 23B. Determine the transit speed correction factors, MCSPD and SCSPD, from Table C-6. Enter these values on lines 23A and 23B, respectively. Selection of the correction factors will be dependent on the maximum transit speeds noted on line 9.

24A and 24B. Determine the channel width correction factors, MCWID and SCWID, from Table C-7. Enter these values on lines 24A and 24B respectively. Selection of the correction factors will be dependent on the channel width noted on line 4.

25. Calculate the adjusted crosstrack mean MN' as the product of lines 21A, 22A, 23A, and 24A. Enter on line 25.

26. Calculate the adjusted crosstrack standard deviation, SD', as the product of lines 21B, 22B, 23B, and 24B. Enter on line 26.

27. Enter the ship length (L) from line 10 on line 27.

28. Enter the crosstrack current component, VX, from line 5 on line 28.

29. Enter the minimum expected transit speed, VMIN, from line 8 on line 29.

30. Enter the ship's beam, B, from line 11 on line 30.

31. Calculate the adjusted beam, B', using the formula indicated from lines 27 through 30. Enter the result on line 31.

32A and 32B. Enter the channel width, W, from line 4 on lines 32A and 32B.

33A and 33B. Enter the adjusted mean, MN', from line 25 on lines 33A and 33B.

34A and 34B. Enter the adjusted beam, B', from line 31 on lines 34A and 34B.

35A and 35B. Enter the adjusted standard deviation, SD', from line 26 on lines 35A and 35B.

36. Calculate the standard deviation multiples to starboard, NS, according to the formula indicated on lines 32A, 33A, 34A, and 35A. Enter the result on line 36.

37. Calculate the standard deviation multiples to port, NP, according to the formula indicated on lines 32B, 33B, 34B, and 35B. Enter the result on line 37.

38. Determine the probability of crossing the starboard channel edge, PS, using Table C-1 and the value of NS from line 36. Enter the result on line 38.

39. Determine the probability of crossing the port channel edge, PP, using Table C-1 and the value of NP from line 36. Enter the result on line 39.

40. Calculate the relative risk factor RRF as the sum of lines 38 and 39. Enter the sum on line 40.

C.3 CALCULATION OF RRF FOR RECOVERY REGIONS

This section provides instructions and data required to calculate the relative risk factor for recovery regions. The calculation is conducted on a tabulation Form YYY provided as Figure C-2. The numbered instructions correspond to their identical numbered boxes on Form YYY. The piloting performance data and correction factors are provided in Tables C-8 through C-13. In those tables the notations D48, D49, etc., refer to explanatory notes on pages C-51 through C-62.

FORM YYY

CALCULATION OF RRF: RECOVERY REGION

CHANNEL IDENTIFICATION

1. CHANNEL NAME AND LOCATION	2. CHART NO.
3. LATITUDE AND LONGITUDE OF MID POINT	

CHANNEL AND ENVIRONMENTAL PARAMETERS

4. ENTER CHANNEL WIDTH (FEET)	W= FT
5. ENTER MAXIMUM CROSS CURRENT COMPONENT (KNOTS)	VX= KTS
6. ENTER MAXIMUM WIND VELOCITY (KNOTS)	VW= KTS

DESIGN VESSEL PARAMETERS

7. ENTER SHIP TYPE AND DWT	
8. ENTER MINIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMIN= KTS
9. ENTER MAXIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMAX= KTS
10. ENTER SHIPS LENGTH (FEET)	L= FT
11. ENTER SHIPS BEAM (FEET)	B= FT

SRA DESIGN PARAMETERS (CIRCLE ONE)

12. AN DETECTION DISTANCE	LESS THAN AN SPACING (RADAR)	GREATER THAN AN SPACING (VISUAL)	
13. DAYLIGHT CONDITIONS	DAY	NIGHT, DUSK OR DAWN	
14. AN CONFIGURATION: (IF RADAR)	GATED LO SENS RNG RACON LEADING MARK	STAGGERED HI SENS RNG RACON RANGES	ONE-SIDE
15. AN SPACING	5/8 NM	1 NM	1 1/4 NM
16. TRAFFIC CONDITION	ONE WAY	TWO WAY	
17. MAX EXPECTED DRIFT ANGLE	$\tan^{-1}\left(\frac{\text{LINE 5}}{\text{LINE 8}}\right)$ =	DA= DEG	

RADIO AID DESIGN PARAMETERS (CIRCLE ONE)

18. GYRO AIDING	YES	NO	
19. RMS NOISE AT SITE (METERS)	0 TO 6 M	6 TO 18 M	18 TO 36 M
20. DISPLAY FORMAT	GRAPHIC W/VECTOR / PERSPECTIVE	GRAPHIC W/PREDICTOR / DIGITAL/DISTANCE	DIGITAL/TURN
21. THROUGH SYSTEM RISE TIME	3 SEC	12 SEC	24 SEC

CALCULATE ADJUSTED MN AND SD

21A ENTER BASELINE MEAN TABLE C.8,C.9,C.10 MN	22A ENTER MEAN SHIP CORRECTION FACTOR TABLE C.11 MCSHP	24A ENTER MEAN SPEED CORRECTION FACTOR TABLE C.12 MCSPO	25A ENTER MEAN WIDTH CORRECTION FACTOR TABLE C.12 MCWID		26 CALCULATE ADJUSTED MEAN MN'
(FT)x(	)x(	)x(	)	=	(FT)

21B ENTER BASELINE STD. DEV. 1 TABLE C.8,C.9,C.10 SD	22B ENTER S.D. SHIP CORRECTION FACTOR TABLE C.11 SCSHP	24B ENTER S.D. SPEED CORRECTION FACTOR TABLE C.12 SCSPD	25B ENTER S.D. WIDTH CORRECTION FACTOR TABLE C.12 SCWID		27 CALCULATE ADJUSTED STD. DEV. SD'
(FT)x(	)x(	)x(	)	=	(FT)

CALCULATE ADJUSTED BEAM

28 ENTER SHIP LENGTH LINE 10 L	29 ENTER CROSS TRACK CURRENT VELOCITY LINE 5 VX	30 ENTER MINIMUM EXPECTED SPEED LINE 8 VMIN		31 ENTER SHIPS BEAM LINE 11 B		32 CALCULATE ADJUSTED BEAM B'
(/2)x(	/	)	+	(/2)	=	(FT)

CALCULATE THE RELATIVE RISK FACTOR

33A ENTER CHAN. WIDTH LINE 4 W	34A ENTER ADJUSTED MEAN LINE 26 MN'	35A ENTER ADJUSTED BEAM LINE 32 B'		36A ENTER ADJUSTED STD. DEV. LINE 27 SD'		37 CALCULATE S.D. MULTIPLE TO STARBOARD NS
(/2)−(	)−(	)	/	( )	=	( )

33B ENTER CHAN. WIDTH LINE 4 W	34B ENTER ADJUSTED MEAN LINE 26 MN'	35B ENTER CHAN. ADJUSTED BEAM LINE 32 B'		36B ENTER ADJUSTED STD. DEV. LINE 27 SD'		38 CALCULATE S.D. MULTIPLE TO PORT NP
(/2)+(	)−(	)	/	( )	=	( )

39 DETERMINE PROB. OF CROSSING NS TABLE C.1 PS	40 DETERMINE PROB. OF CROSSING NP TABLE C.1 PP		41 CALCULATE RELATIVE RISK FACTOR RRF
( )+(	)	=	( )

Figure C-2. Calculation of Relative Risk Factor for Recovery Regions, Form YYY

TABLE C-8. BASELINE VALUES FOR MN AND SD, RECOVERY REGION, VISUAL PILOTING

LINE 12: AN DETECTION DISTANCE — GREATER THAN AN SPACING (VISUAL PILOTING)

LINE 13: DAYLIGHT CONDITION — DAY, NIGHT, DUSK, DAWN

LINE 16: TRAFFIC CONDITION; LINE 17: MAX DRIFT ANGLE

LINE 14: AN CONFIGURATION	LINE 15: AN SPACING	ONE WAY TRAFFIC, 0 TO 2 DEG, MN : SD	ONE WAY TRAFFIC, 2 TO 5 DEG, MN : SD	TWO WAY TRAFFIC (NOTE A), 0 TO 2 DEG, MN : SD	TWO WAY TRAFFIC (NOTE A), 2 TO 5 DEG, MN : SD
GATED	5/8 NM	6 : 40 (D48)	81 : 46 (D49)	(W/6) + 6 : 40 (D65)	(W/6) + 81 : 46 (D65)
GATED	1 NM	5 : 40 (D50)	83 : 46 (D50)	(W/6) + 5 : 40 (D65)	(W/6) + 83 : 46 (D65)
GATED	1 1/4 NM	4 : 40 (D51)	85 : 45 (D52)	(W/6) + 4 : 40 (D65)	(W/6) + 85 : 45 (D65)
STAGGERED	5/8 NM	16 : 40 (D53)	90 : 56 (D54)	(W/6) + 16 : 40 (D65)	(W/6) + 90 : 56 (D65)
STAGGERED	1 NM	27 : 53 (D50)	92 : 61 (D50)	(W/6) + 27 : 53 (D65)	(W/6) + 92 : 61 (D65)
STAGGERED	1 1/4 NM	37 : 65 (D55)	93 : 65 (D56)	(W/6) + 37 : 65 (D65)	(W/6) + 93 : 65 (D65)
ONE SIDE	5/8 NM	23 : 41 (D57)	121 : 92 (D58)	(W/6) + 23 : 41 (D65)	(W/6) + 121 : 92 (D65)
ONE SIDE	1 NM	15 : 44 (D50)	116 : 86 (D50)	(W/6) + 15 : 44 (D65)	(W/6) + 116 : 86 (D65)
ONE SIDE	1 1/4 NM	7 : 47 (D59)	111 : 79 (D60)	(W/6) + 7 : 47 (D65)	(W/6) + 111 : 79 (D65)
RANGE LIGHTS	HIGH SENS	15 : 25 (D61)	111 : 127 (D62)	(W/6) + 15 : 25 (D65)	(W/6) + 111 : 127 (D65)
RANGE LIGHTS	LO SENS	44 : 53 (D63)	18 : 170 (D64)	(W/6) + 44 : 53 (D65)	(W/6) + 18 : 170 (D65)

NOTE A: FOR TWO WAY TRAFFIC ADD 1/6 OF THE CHANNEL WIDTH (LINE 4) TO THE BASE LINE VALUE OF MN AS INDICATED. IT IS ASSUMED THAT THE STANDARD DEVIATION IS NOT AFFECTED BY TWO WAY TRAFFIC.

TABLE C-9. BASELINE VALUES FOR MN AND SD, RECOVERY REGIONS, RADAR PILOTING

LINE 12: AN DETECTION DISTANCE: LESS THAN AN SPACING (RADAR PILOTING)

LINE 13: DAYLIGHT CONDITION: DAY,NIGHT,DUSK,DAWN

LINE 16: TRAFFIC CONDITION

LINE 17: MAX DRIFT ANGLE

LINE 14: AN CONFIGURATION	LINE 15: AN SPACING	ONE WAY TRAFFIC, 0 TO 2 DEG (MN : SD)	ONE WAY TRAFFIC, 2 TO 5 DEG (MN : SD)	TWO WAY TRAFFIC, 0 TO 2 DEG (MN : SD)	TWO WAY TRAFFIC, 2 TO 5 DEG (MN : SD)
GATED	5/8 NM	DATA NOT AVAILABLE		DATA NOT AVAILABLE	
	1 NM				
	1 1/4 NM				
STAGGERED	5/8 NM				
	1 NM				
	1 1/4 NM				
ONE SIDE	5/8 NM				
	1 NM				
	1 1/4 NM				
RACON	LEADING MARK, RACON RANGE				

TABLE C-10. BASELINE VALUES FOR MN AND SD, RECOVERY REGIONS, RADIO AID PILOTING

LINE 16: TRAFFIC CONDITION — ONE AND TWO WAY TRAFFIC

LINE 17: MAXIMUM DRIFT ANGLE DA

			0 TO 2 DEG	2 TO 5 DEG
			MN : SD	MN : SD
PERFECT POSITION & VELOCITY AVAILABLE		LINE 20: DISPLAY FORMAT		
		GRAPHIC W/ VECTOR	11 : 23 (D66)	42 : 86 (D67)
		GRAPHIC W/ PREDICT	21 : 31 (D68)	30 : 82 (D69)
		PERSPECTIVE	14 : 35 (D70)	150 : 115 (D71)
		DIGITAL/DISTANCE	14 : 30 (D72)	44 : 187 (D73)
		DIGITAL/TURNING	1 : 48 (D74)	122 : 338 (D75)
NO GYRO AIDING IN TRACKER	LINE 19: RMS NOISE AT SITE	LINE 20: DISPLAY FORMAT GRAPHIC W/HDG VECTOR; LINE 20: SYSTEM RISE TIME		
	0 TO 6 M	3 SEC	6 : 29 (D76)	79 : 94 (D77)
	0 TO 6 M	12 SEC	NOTE A	NOTE A
	0 TO 6 M	24 SEC	NOTE A	NOTE A
	6 TO 18 M	3 SEC	2 : 18 (D79)	6 : 53 (D79)
	6 TO 18 M	12 SEC	16 : 42 (D80)	6 : 101 (D81)
	6 TO 18 M	24 SEC	9 : 45 (D82)	43 : 34 (D83)
	18 TO 36 M	3 SEC	11 : 45 (D84)	16 : 74 (D85)
	18 TO 36 M	12 SEC	15 : 44 (D86)	8 : 50 (D87)
	18 TO 36 M	24 SEC	18 : 44 (D88)	31 : 64 (D89)
LINE 18: GYRO AIDING — YES, GYRO AIDING IN TRACKER	LINE 19: RMS NOISE AT SITE	LINE 20: DISPLAY FORMAT GRAPHIC W/HDG VECTOR; LINE 20: SYSTEM RISE TIME		
	0 TO 6 M	3 SEC	NOTE B	NOTE B
	0 TO 6 M	12 SEC	NOTE B	NOTE B
	0 TO 6 M	24 SEC	6 : 28 (D90)	79 : 94 (D91)
	6 TO 18 M	3 SEC	NOTE B	NOTE B
	6 TO 18 M	12 SEC	NOTE B	NOTE B
	6 TO 18 M	24 SEC	1 : 43 (D92)	46 : 62 (D93)
	18 TO 36 M	3 SEC	NOTE B	NOTE B
	18 TO 36 M	12 SEC	NOTE B	NOTE B
	18 TO 36 M	24 SEC	14 : 25 (D94)	3 : 45 (D95)

DATA FROM EXPERIMENT (shaded) INTERPOLATED VALUES (black)

NOTE A. LONG RISE TIMES INTRODUCE LAG ERRORS OF MAGNITUDE GREATER THAN THOSE INTRODUCED BY THE RMS NOISE. RA–1

NOTE B. 24 SEC RISE TIME APPEARS TO BE NEAR OPTIMUM WITH GYRO AIDING. SHORTER RISE TIMES INTRODUCE ERRORS. RA–2

TABLE C-11. SHIP SIZE CORRECTION FACTORS FOR RECOVERY REGIONS

FROM LINE 7: SHIP TYPE AND DWT:	MEAN: SHIP CORRECTION FACTOR MCSHP	STANDARD DEVIATION: CORRECTION FACTOR SCSHP
TANKER, 30,000 DWT	1.0	1.0
TANKER, 80,000 DWT	1 0	1.9
TANKER, 120,000 DWT	DATA NOT YET AVAILABLE	
TANKER, 250,000 DWT		
CONTAINER,		
CONTAINER,		
LNG, 124,000 FT^3		

TABLE C-12. SHIP SPEED CORRECTION FACTORS FOR RECOVERY REGIONS

LINE 9: MAXIMUM EXPECTED SPEED VMAX	LINE 7: SHIP TYPE AND DWT	MCSPD (MEAN AND STANDARD DEVIATION SHIP SPEED CORRECTION FACTORS)	SCSPD
4 TO 8 KNOTS	TANKER 30,000 DWT	1.0	1.0
	TANKER 80,000 DWT	1.0	1.0
	TANKER 120.000 DWT	DATA NOT YET AVAILABLE	DATA NOT YET AVAILABLE
	TANKER 250,000 DWT	DATA NOT YET AVAILABLE	DATA NOT YET AVAILABLE
	CONTAINER	DATA NOT YET AVAILABLE	DATA NOT YET AVAILABLE
	CONTAINER	DATA NOT YET AVAILABLE	DATA NOT YET AVAILABLE
	L.N.G.	DATA NOT YET AVAILABLE	DATA NOT YET AVAILABLE
8 TO 12 KNOTS	TANKER 30,000 DWT	1.3	1.0
	TANKER 80,000 DWT	1.4	1.4
	TANKER 120,000 DWT	DATA NOT YET AVAILABLE	DATA NOT YET AVAILABLE
	CONTAINER	DATA NOT YET AVAILABLE	DATA NOT YET AVAILABLE
	CONTAINER	DATA NOT YET AVAILABLE	DATA NOT YET AVAILABLE
	L.N.G	DATA NOT YET AVAILABLE	DATA NOT YET AVAILABLE

TABLE C-13. CHANNEL WIDTH CORRECTION FACTORS FOR RECOVERY REGIONS

FROM LINE 4: CHANNEL WIDTH: W

$\boxed{W < 500 \text{ FEET*}}$

MCWID = SCWID = 1.0

$\boxed{500 < W < 800 \text{ FEET}}$

MCWID = SCWID = 1 + (.5)(W-500)/(300)

*THE FACTOR 1.0 IS SELECTED AS CONSERVATIVE SINCE EXPERIMENTAL DATA ARE NOT YET AVAILABLE FOR CHANNELS LESS THAN 500 FEET.

Instructions

1. Enter a verbal description of the channel and the waterway or port name.

2. Enter the NOAA chart number which provides a detailed diagram of the existing AN configuration and present bathometry (depth) and dimensions (width).

3. Enter the latitude and longitude of a point midway along the channel region and which is midway between the channel edges.

4. Enter the channel width (feet) as indicated on the chart (or) the width of navigable water with regard to the maximum draft of the user vessels.

5. Enter the maximum current component which flows perpendicular to the channel edges. Enter as a positive value regardless of direction. If none expected, enter 0.0.

6. Enter the maximum wind velocity (knots) which may occur during normal port operations. Enter as a positive value, regardless of direction.

7. Enter the ship type and deadweight tonnage of the least maneuverable vessel expected to utilize the waterway. This will normally be the ship with the largest dwt. Tug and tow and push barges are not presently considered for design purposes.

8. Enter the minimum expected transit speed for the vessel noted in line 7. If unknown, enter 4.0 knots as a worst case value.

9. Enter the maximum expected transit speed for the vessel noted in line 7. This will typically be the vessel's full ahead maneuvering speed, not its full capability sea speed.

10. Enter the length (feet) of the vessel noted in line 7.

11. Enter the beam (feet) of the vessel noted in line 7.

NOTE: If visual or radar piloting techniques are to be evaluated, complete instructions 12 through 17. If radio and piloting techniques are to be evaluated, complete instructions 18 through 21.

12. Circle the AN detection distance for which RRF is to be determined. The AN detection distance is taken to be the distance at which 50 percent of the pilots will see the AN. Radar piloting techniques are assumed for detection distances less than the AN spacing. Visual piloting techniques are assumed for detection distances greater than the AN spacing.

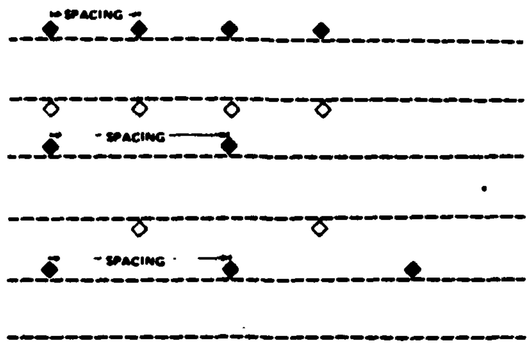
13. Circle the daylight conditions for which the RRF is to be determined. Night, dusk, and dawn are conservatively assumed to be the same condition.

14. Circle the AN configuration for which the RRF is to be calculated. Only those configurations shown below apply.

Gated

Staggered

One side



For channels which are marked with range lights, denote the range sensitivity as selected from the table below.

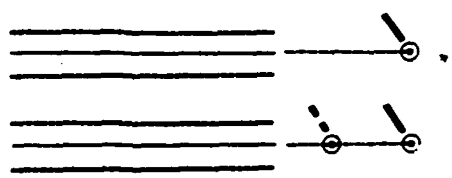
	K*	X_Q*
High sensitivity range	0.5 to 0.8	1.5 to 6 feet
Low sensitivity range	3.5 to 10.0	20 to 40 feet

*See Coast Guard Publication 39B for calculation of the values of lateral sensitivity K and crosstrack position X for the θ Q displacement (i.e., X_Q).

For channels which are marked only with racons and no buoys exist along the channel, denote the racon configuration as either a (single) "racon leading mark" or a (double) "racon range."

Racon leading mark

Racon range



15. If gated, staggered, or one-side is circled in line 14, circle the AN spacing for which the RRF is to be calculated. The spacing assumed is indicated on the diagrams above.

16. Circle the traffic condition for which the relative RRF is to be calculated. One way traffic is indicated for special operations and infrequent transits.

17. Enter the value for maximum crosscurrent, VX, from line 5 and the minimum expected transit speed, VMIN, from line 8 in the positions indicated. Calculate the resultant drift angle, DA, as the inverse tangent of VX/VMIN. Enter the result (in degrees) on line 17.

NOTE: If radio aids are not to be considered continue with instruction 22A and 22B.

18. Circle whether or not a ship's gyro heading signal is utilized to improve tracking accuracy in turns.

19. Circle the bounds of RMS signal noise measured at the site (meters). Do not include bias errors.

20. Circle the radio aid display format to be utilized in accordance with the following minimum operating characteristics:

- Graphic with vector: PPI type display, selectable range scale (3/4 nm minimum), course and/or heading vector, ship's hull image to scale

- Graphic with predictor: PPI type display, selectable range scale (3/4 nm minimum), position predictor vector based on hydrodyamic model of the vessel, ship's hull image to scale

- Perspective: CRT type display, maximum field of view 60 degrees, channel edges indicated as lines, ship's bow image

- Digital with distance: Digital readout of the following data: distance off centerline, crosstrack velocity, distance to waypoint

- Digital with turning: Digital readout of the following data: distance off centerline, crosstrack velocity, distance to waypoint, turn rate, recommended turn rate*

*Recommended turn rate is that turn rate which will achieve a tangential intersection between the ship's course and the centerline of the next leg given the ship's present position, course, and speed.

21. Circle the through system rise time. This is the time required for the displayed position to equal 0.667 of the value of a step change in the input signal value. The through system rise time accounts for the response of both the receiver and any additional trackers (filters) in the system.

22A and 22B. Determine the baseline values of MN and SD from Tables C-8, C-9 or C-10. Utilize Table C-8 if the AN detection distance (line 12) is greater than the assumed AN spacing (line 15) and visual piloting is assumed. Utilize Table C-9 if the AN detection distance (line 12) is less than the assumed AN spacing (line 15) and radar piloting is assumed. Utilize Table C-10 if radio aid display piloting is assumed. Enter these values on lines 22A and 22B respectively. Selection of the baseline values for visual or radar navigation will be dependent on the parameters circled on lines 12 through 17. Selection of the baseline values for radio aid navigation will be dependent on the parameters circled on lines 18 through 21.

23A and 23B. Determine the ship size correction factors, MCSHP and SCSHP, from Table C-11. Enter these values on lines 23A and 23B respectively. Selection of the correction factors will be dependent on the ship size noted on line 7.

24A and 24B. Determine the transit speed correction factors, MCSPD and SCSPD, from Table C-12. Enter these values on lines 24A and 24B, respectively. Selection of the correction factors will be dependent on the maximum transit speeds noted on line 9.

25A and 25B. Determine the channel width correction factors, MCWID and SCWID, from Table C-13. Enter these values on lines 25A and 25B respectively. Selection of the correction factors will be dependent on the channel width noted on line 4.

26. Calculate the adjusted crosstrack mean MN' as the product of lines 22A, 23A, 24A, and 25A. Enter on line 26.

27. Calculate the adjusted crosstrack standard deviation, SD', as the product of lines 22B, 23B, 24B, and 25B. Enter on line 27.

28. Enter the ship length (L) from line 10 on line 28.

29. Enter the crosstrack current component, VX, from line 5 on line 29.

30. Enter the minimum expected transit speed, VMIN, from line 8 on line 30.

31. Enter the ship's beam, B, from line 11 on line 31.

32. Calculate the adjusted beam, B', using the formula indicated from lines 28 through 31. Enter the result on line 32.

33A and 33B. Enter the channel width, W, from line 4 on lines 33A and 33B.

34A and 34B. Enter the adjusted mean, MN', from line 26 on lines 34A and 34B.

35A and 35B. Enter the adjusted beam, B', from line 32 on lines 35A and 35B.

36A and 36B. Enter the adjusted standard deviation, SD', from line 27 on lines 36A and 36B.

37. Calculate the standard deviation multiples to starboard, NS, according to the formula indicated on lines 33A, 34A, 35A, and 36A. Enter the result on line 37.

38. Calculate the standard deviation multiples to port, NP, according to the formula indicated on lines 33B, 34B, 35B, and 36B. Enter the result on line 38.

39. Determine the probability of crossing the starboard channel edge, PS, using Table C-1 and the value of NS from line 37. Enter the result on line 39.

40. Determine the probability of crossing the port channel edge, PP, using Table C-1 and the value of NP from line 37. Enter the result on line 40.

41. Calculate the relative risk factor RRF as the sum of lines 39 and 40. Enter the sum on line 41.

C.4 CALCULATION OF RRF FOR TRACKKEEPING REGIONS

This section provides instructions and data required to calculate the relative risk factor for trackkeeping regions. The calculation is conducted on a tabulation Form ZZZ provided as Figure C-3. The numbered instructions correspond to their identical numbered boxes on Form ZZZ. The piloting performance data and correction factors are provided in Tables C-14 through C-19. In those tables the notations D96, D97, etc., refer to explanatory notes on pages C-51 through C-62.

Instructions

1. Enter a verbal description of the channel and the waterway or port name.

2. Enter the NOAA chart number which provides a detailed diagram of the existing AN configuration and present bathometry (depth) and dimensions (width).

3. Enter the latitude and longitude of a point midway along the channel region and which is midway between the channel edges.

4. Enter the channel width (feet) as indicated on the chart (or) the width of navigable water with regard to the maximum draft of the user vessels.

5. Enter the maximum current component which flows perpendicular to the channel edges. Enter as a positive value regardless of direction. If none expected, enter 0.0.

6. Enter the maximum wind velocity (knots) which may occur during normal port operations. Enter as a positive value regardless of direction.

7. Enter the ship type and deadweight tonnage of the least maneuverable vessel expected to utilize the waterway. This will normally be the ship with the largest dwt. Tug and tow and push barges are not presently considered for design purposes.

8. Enter the minimum expected transit speed for the vessel noted in line 7. If unknown, enter 4.0 knots as a worst case value.

FORM ZZZ

CALCULATION OF RRF: TRACK KEEPING REGION

CHANNEL IDENTIFICATION

1. CHANNEL NAME AND LOCATION	2. CHART NO.
3. LATITUDE AND LONGITUDE OF CHANNEL MIDPOINT	

CHANNEL AND ENVIRONMENTAL PARAMETERS

4. ENTER CHANNEL WIDTH (FEET)	W= FT
5. ENTER MAXIMUM CROSS CURRENT COMPONENT (KNOTS);	VX= KTS
6. ENTER MAXIMUM WIND VELOCITY (KNOTS)	VW= KTS

DESIGN VESSEL PARAMETERS

7. ENTER SHIP TYPE AND DWT	
8. ENTER MINIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMIN= KTS
9. ENTER MAXIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMAX= KTS
10. ENTER SHIPS LENGTH (FEET)	L= FT
11. ENTER SHIPS BEAM (FEET)	B= FT

SRA DESIGN PARAMETERS (CIRCLE ONE)

12. AN DETECTION DISTANCE	LESS THAN AN SPACING (RADAR)		GREATER THAN AN SPACING (VISUAL)
13. DAYLIGHT CONDITIONS	DAY		NIGHT, DUSK OR DAWN
14. AN CONFIGURATION: (IF RADAR):	GATED LO SENS RNG RACON LEADING MARK	STAGGERED	ONE-SIDE HI SENS RNG RACON RANGES
15. AN SPACING	5/8 NM	1 NM	1 1/4 NM
16. TRAFFIC CONDITION	ONE WAY		TWO WAY
17. MAX EXPECTED DRIFT ANGLE	TAN^{-1}(LINE 5 / LINE 8) =	DA= DEG	

RADIO AID DESIGN PARAMETERS (CIRCLE ONE)

18. GYRO AIDING	YES		NO
19. RMS NOISE AT SITE (METERS)	0 TO 6 M	6 TO 18 M	18 TO 36 M
20. DISPLAY FORMAT	GRAPHIC W/VECTOR PERSPECTIVE	DIGITAL/DISTANCE	GRAPHIC W/PREDICTOR DIGITAL/TURN
21. THROUGH SYSTEM RISE TIME	3 SEC	12 SEC	24 SEC

CALCULATE ADJUSTED MN AND SD

21A ENTER BASELINE MEAN TABLE C.14,C.15,C.16 MN	22A ENTER MEAN SHIP CORRECTION FACTOR TABLE C.17 MCSHP	24A ENTER MEAN SPEED CORRECTION FACTOR TABLE C.18 MCSPD	25A ENTER MEAN WIDTH CORRECTION FACTOR TABLE C.19 MCWID		26 CALCULATE ADJUSTED MEAN MN'
(FT)x(	)x(	)x(	)	=	(FT)

22B ENTER BASELINE STD. DEV. 1 TABLE C.14,C.15,C.16 SD	23B ENTER S.D. SHIP CORRECTION FACTOR TABLE C.17 SCSHP	24B ENTER S.D. SPEED CORRECTION FACTOR TABLE C.18 SCSPD	25B ENTER S.D. WIDTH CORRECTION FACTOR TABLE C.19 SCWID		27 CALCULATE ADJUSTED STD. DEV. SD'
(FT)x(	)x(	)x(	)	=	(FT)

CALCULATE ADJUSTED BEAM

28 ENTER SHIP LENGTH LINE 10 L	29 ENTER CROSS TRACK CURRENT VELOCITY LINE 5 VX	30 ENTER MINIMUM EXPECTED SPEED LINE 8 VMIN		31 ENTER SHIPS BEAM LINE 11 B		32 CALCULATE ADJUSTED BEAM B'
(/2)x(		)	+	(/2)	=	(FT)

CALCULATE THE RELATIVE RISK FACTOR

33A ENTER CHAN. WIDTH LINE 4 W	34A ENTER ADJUSTED MEAN LINE 26 MN'	35A ENTER ADJUSTED BEAM LINE 32 B'		36A ENTER ADJUSTED STD. DEV. LINE 27 SD'		37 CALCULATE S.D. MULTIPLE TO STARBOARD NS
((/2)-(	)-(	))	/	( )	=	( )

33B ENTER CHAN. WIDTH LINE 4 W	34B ENTER ADJUSTED MEAN LINE 26 MN'	35B ENTER CHAN. ADJUSTED BEAM LINE 32 B'		36B ENTER ADJUSTED STD. DEV. LINE 27 SD'		38 CALCULATE S.D. MULTIPLE TO PORT NP
((/2)+(	)-(	))	/	( )	=	( )

39 DETERMINE PROB. OF CROSSING NS TABLE C.1 PS	40 DETERMINE PROB. OF CROSSING NP TABLE C.1 PP		41 CALCULATE RELATIVE RISK FACTOR RRF
( )+(	)	=	( )

Figure C-3. Calculation of Relative Risk Factor for Trackkeeping Regions, Data Form ZZZ

TABLE C-14. BASELINE VALUES FOR MN AND SD TRACKKEEPING REGION, VISUAL PILOTING

LINE 12: AN DETECTION DISTANCE — GREATER THAN AN SPACING (VISUAL PILOTING)
LINE 13: DAYLIGHT CONDITION — DAY, NIGHT, DUSK, DAWN

LINE 16: TRAFFIC CONDITION		ONE WAY TRAFFIC		TWO WAY TRAFFIC (NOTE A)	
LINE 17: MAX DRIFT ANGLE		0 TO 2 DEG	2 TO 5 DEG	0 TO 2 DEG	2 TO 5 DEG
LINE 14: AN CONFIGURATION	LINE 15: AN SPACING	MN : SD	MN : SD	MN : SD	MN : SD
GATED	5/8 NM	7 : 37 (D96)	30 : 53 (D97)	(W/6) + 7 : 37 (D113)	(W/6) + 30 : 53 (D113)
	1 NM	4 : 36 (D98)	51 : 51 (D98)	(W/6) + 4 : 36 (D113)	(W/6) + 51 : 51 (D113)
	1 1/4 NM	0 : 34 (D99)	72 : 48 (D100)	(W/6) + 0 : 34 (D113)	(W/6) + 72 : 48 (D113)
STAGGERED	5/8 NM	0 : 37 (D101)	63 : 69 (D102)	(W/6) + 0 : 37 (D113)	(W/6) + 63 : 69 (D113)
	1 NM	16 : 44 (D98)	52 : 69 (D98)	(W/6) + 16 : 44 (D113)	(W/6) + 52 : 69 (D113)
	1 1/4 NM	32 : 52 (D103)	41 : 68 (D104)	(W/6) + 32 : 52 (D113)	(W/6) + 41 : 68 (D113)
ONE SIDE	5/8 NM	23 : 41 (D105)	119 : 81 (D106)	(W/6) + 23 : 41 (D113)	(W/6) + 119 : 81 (D113)
	1 NM	15 : 44 (D98)	119 : 79 (D98)	(W/6) + 15 : 44 (D113)	(W/6) + 119 : 79 (D113)
	1 1/4 NM	7 : 47 (D107)	119 : 76 (D108)	(W/6) + 7 : 47 (D113)	(W/6) + 119 : 76 (D113)
RANGE LIGHTS	HIGH SENS	2 : 12 (D109)	4 : 12 (D110)	(W/6) + 2 : 12 (D113)	(W/6) + 4 : 12 (D113)
	LO SENS	4 : 53 (D111)	53 : 87 (D112)	(W/6) + 4 : 53 (D113)	(W/6) + 53 : 87 (D113)

NOTE A: FOR TWO WAY TRAFFIC ADD 1/6 OF THE CHANNEL WIDTH (LINE 4) TO THE BASE LINE VALUE OF MN AS INDICATED. IT IS ASSUMED THAT THE STANDARD DEVIATION IS NOT AFFECTED BY TWO WAY TRAFFIC.

TABLE C-15. BASELINE VALUES FOR MN AND SD, TRACKKEEPING REGION, RADAR PILOTING

LINE 12: AN DETECTION DISTANCE: LESS THAN AN SPACING (RADAR PILOTING)

LINE 13: DAYLIGHT CONDITION: DAY,NIGHT,DUSK,DAWN

LINE 16: TRAFFIC CONDITION		ONE WAY TRAFFIC		TWO WAY TRAFFIC	
LINE 17: MAX DRIFT ANGLE		0 TO 2 DEG	2 TO 5 DEG	0 TO 2 DEG	2 TO 5 DEG
LINE 14: AN CONFIGURATION	LINE 15: AN SPACING	MN : SD	MN : SD	MN : SD	MN : SD
GATED	5/8 NM	DATA NOT AVAILABLE		DATA NOT AVAILABLE	
	1 NM				
	1 1/4 NM				
STAGGERED	5/8 NM				
	1 NM				
	1 1/4 NM				
ONE SIDE	5/8 NM				
	1 NM				
	1 1/4 NM				
RACON	LEADING MARK.				
	RACON RANGE				

TABLE C-16. BASELINE VALUES FOR MN AND SD TRACKKEEPING REGIONS, RADIO AID PILOTING

LINE 16: TRAFFIC CONDITION — ONE AND TWO WAY TRAFFIC

LINE 17: MAXIMUM DRIFT ANGLE DA

				0 TO 2 DEG MN : SD	2 TO 5 DEG MN : SD
PERFECT POSITION & VELOCITY DATA AVAILABLE		LINE 20: DISPLAY FORMAT	GRAPHIC W/ VECTOR	12 : 36 (D114)	30 : 58 (D115)
			GRAPHIC W/ PREDICT	48 : 51 (D116)	17 : 50 (D117)
			PERSPECTIVE	35 : 31 (D118)	150 : 107 (D119)
			DIGITAL/DISTANCE	11 : 23 (D120)	41 : 89 (D121)
			DIGITAL/TURNING	1 : 25 (D122)	118 : 339 (D123)
NO GYRO AIDING IN TRACKER	LINE 19: RMS NOISE AT SITE 0 TO 6 M	LINE 20: DISPLAY FORMAT GRAPHIC W/HDG VECTOR	LINE 20: SYSTEM RISE TIME 3 SEC	10 : 44 (D124)	60 : 62 (D125)
			12 SEC	NOTE A	NOTE A
			24 SEC	NOTE A	NOTE A
	6 TO 18 M		3 SEC	6 : 19 (D126)	10 : 46 (D127)
			12 SEC	16 : 42 (D128)	25 : 43 (D129)
			24 SEC	15 : 18 (D130)	1 : 43 (D131)
	18 TO 36 M		3 SEC	6 : 33 (D132)	3 : 52 (D133)
			12 SEC	3 : 26 (D134)	8 : 50 (D135)
			24 SEC	9 : 34 (D136)	25 : 37 (D137)
LINE 18: GYRO AIDING — YES, GYRO AIDING IN TRACKER	LINE 19: RMS NOISE AT SITE 0 TO 6 M	LINE 20: DISPLAY FORMAT GRAPHIC W/HDG VECTOR	LINE 20: SYSTEM RISE TIME 3 SEC	NOTE B	NOTE B
			12 SEC	NOTE B	NOTE B
			24 SEC	10 : 44 (D138)	60 : 62 (D139)
	6 TO 18 M		3 SEC	NOTE B	NOTE B
			12 SEC	NOTE B	NOTE B
			24 SEC	2 : 19 (D140)	7 : 49 (D141)
	18 TO 36 M		3 SEC	NOTE B	NOTE B
			12 SEC	NOTE B	NOTE B
			24 SEC	4 : 30 (D142)	13 : 47 (D143)

DATA FROM EXPERIMENT (shaded) — INTERPOLATED VALUES (black)

NOTE A. LONG RISE TIMES INTRODUCE LAG ERRORS OF MAGNITUDE GREATER THAN THOSE INTRODUCED BY THE RMS NOISE. RA–1

NOTE B. 24 SEC RISE TIME APPEARS TO BE NEAR OPTIMUM WITH GYRO AIDING. SHORTER RISE TIMES INTRODUCE ERRORS. RA–2

TABLE C-17. SHIP SIZE CORRECTION FACTORS FOR TRACKKEEPING REGIONS

FROM LINE 7:

SHIP TYPE AND DWT:	MEAN: SHIP CORRECTION FACTOR MCSHP	STANDARD DEVIATION: CORRECTION FACTOR SCSHP
TANKER, 30,000 DWT	1.0	1.0
TANKER, 80,000 DWT	1.0	1.6
TANKER, 120,000 DWT	DATA NOT YET AVAILABLE	
TANKER, 250,000 DWT		
CONTAINER,		
CONTAINER,		
LNG, 124,000 FT^3		

TABLE C-18. SHIP SPEED CORRECTION FACTORS FOR TRACKKEEPING REGIONS

MEAN AND STANDARD DEVIATION SHIP SPEED CORRECTION FACTORS

LINE 9: MAXIMUM EXPECTED SPEED VMAX	LINE 7: SHIP TYPE AND DWT	MCSPD	SCSPD
4 TO 8 KNOTS	TANKER 30,000 DWT	1.0	1.0
	TANKER 80,000 DWT	1.0	1.0
	TANKER 120,000 DWT	DATA NOT YET AVAILABLE	
	TANKER 250,000 DWT		
	CONTAINER		
	CONTAINER		
	L.N.G.		
8 TO 12 KNOTS	TANKER 30,000 DWT	1.0	1.0
	TANKER 80,000 DWT	1.0	1.0
	TANKER 120,000 DWT	DATA NOT YET AVAILABLE	
	CONTAINER		
	CONTAINER		
	L.N.G		

TABLE C-19. CHANNEL WIDTH CORRECTION FACTORS FOR TRACKEEPING REGIONS

FROM LINE 4: CHANNEL WIDTH: W

$\boxed{W < 500 \text{ FEET*}}$

MCWID = SCWID = 1.0

$\boxed{500 < W < 800 \text{ FEET}}$

MCWID = SCWID = 1 + (.5)(W-500)/(300)

*THE FACTOR 1.0 IS SELECTED AS CONSERVATIVE SINCE EXPERIMENTAL DATA ARE NOT YET AVAILABLE FOR CHANNELS LESS THAN 500 FEET.

9. Enter the maximum expected transit speed for the vessel noted in line 7. This will typically be the vessel's full ahead maneuvering speed, not its full capability sea speed.

10. Enter the length (feet) of the vessel noted in line 7.

11. Enter the beam (feet) of the vessel noted in line 7.

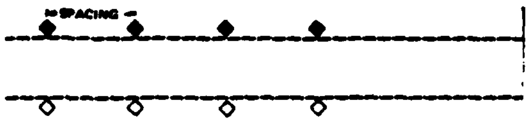
NOTE: If visual or radar piloting techniques are to be evaluated complete instructions 12 through 17. If radio and piloting techniques are to be evaluated, complete instructions 18 through 21.

12. Circle the AN detection distance for which RRF is to be determined. The AN detection distance is taken to be the distance at which 50 percent of the pilots will see the AN. Radar piloting techniques are assumed for detection distances less than the AN spacing. Visual piloting techniques are assumed for detection distances greater than the AN spacing.

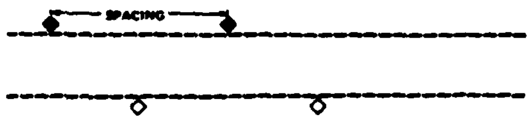
13. Circle the daylight conditions for which the RRF is to be determined. Night, dusk, and dawn are conservatively assumed to be the same condition.

14. Circle the AN configuration for which the RRF is to be calculated. Only those configurations shown below apply.

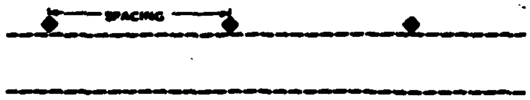
Gated



Staggered



One side

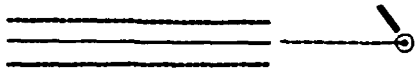


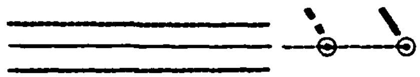
For channels which are marked with range lights, denote the range sensitivity as selected from the table below.

	K*	X_Q*
High sensitivity range	0.5 to 0.8	1.5 to 6 feet
Low sensitivity range	3.5 to 10.0	20 to 40 feet

*See Coast Guard Publication 39B for calculation of the values of lateral sensitivity K and crosstrack position X for the Θ_Q displacement (i.e., X_Q).

For channels which are marked only with racons and no buoys exist along the channel, denote the racon configuration as either a (single) "racon leading mark" or a (double) "racon range."

Racon leading mark 

Racon range 

15. If gated, staggered, or one-side is circled in line 14, circle the AN spacing for which the RRF is to be calculated. The spacing assumed is indicated on the diagrams above.

16. Circle the traffic condition for which the relative RRF is to be calculated. One way traffic is indicated for special operations and infrequent transits.

17. Enter the value for maximum crosscurrent, VX, from line 5 and the minimum expected transit speed, VMIN, from line 8 in the positions indicated. Calculate the resultant drift angle, DA, as the inverse tangent of VX/VMIN. Enter the result (in degrees) on line 17.

NOTE: If radio aids are not to be considered, continue with instruction 22A and 22B.

18. Circle whether or not a ship's gyro heading signal is utilized to improve tracking accuracy in turns.

19. Circle the bounds of RMS signal noise measured at the site (meters). Do not include bias errors.

20. Circle the radio aid display format to be utilized in accordance with the following minimum operating characteristics:

- Graphic with vector: PPI type display, selectable range scale (3/4 nm minimum), course and/or heading vector, ship's hull image to scale

- Graphic with predictor: PPI type display, selectable range scale (3/4 nm minimum), position predictor vector based on hydrodynamic model of the vessel, ship's hull image to scale

- Perspective: CRT type display, maximum field of view 60 degrees, channel edges indicated as lines, ship's bow image

- Digital with distance: Digital readout of the following data: distance off centerline, crosstrack velocity, distance to waypoint

- Digital with turning: Digital readout of the following data: distance off centerline, crosstrack velocity, distance to waypoint, turn rate, recommended turn rate*

*Recommended turn rate is that turn rate which will achieve a tangential intersection between the ship's course and the centerline of the next leg given the ship's present position, course, and speed.

21. Circle the through system rise time. This is the time required for the displayed position to equal 0.667 of the value of a step change in the input signal value. The through system rise time accounts for the response of both the receiver and any additional trackers (filters) in the system.

22A and 22B. Determine the baseline values of MN and SD from Tables C-14, C-15 or C-16. Utilize Table C-14 if the AN detection distance (line 12) is greater than the assumed AN spacing (line 15) and visual piloting is assumed. Utilize Table C-15 if the AN detection distance (line 12) is less than the assumed AN spacing (line 15) and radar piloting is assumed. Utilize Table C-16 if radio aid display piloting is assumed. Enter these values on lines 22A and 22B respectively. Selection of the baseline values for visual or radar navigation will be dependent on the parameters circled on lines 12 through 17. Selection of the baseline values for radio aid navigation will be dependent on the parameters circled on lines 18 through 21.

23A and 23B. Determine the ship size correction factors, MCSHP and SCSHP, from Table C-17. Enter these values on lines 23A and 23B respectively. Selection of the correction factors will be dependent on the ship size noted on line 7.

24A and 24B. Determine the transit speed correction factors, MCSPD and SCSPD, from Table C-18. Enter these values on lines 24A and 24B, respectively. Selection of the correction factors will be dependent on the maximum transit speeds noted on line 9.

25A and 25B. Determine the channel width correction factors, MCWID and SCWID, from Table C-19. Enter these values on lines 25A and 25B respectively. Selection of the correction factors will be dependent on the channel width noted on line 4.

26. Calculate the adjusted crosstrack mean MN' as the product of lines 22A, 23A, 24A, and 25A. Enter on line 26.

27. Calculate the adjusted crosstrack standard deviation, SD', as the product of lines 22B, 23B, 24B, and 25B. Enter on line 27.

28. Enter the ship length (L) from line 10 on line 28.

29. Enter the crosstrack current component, VX, from line 5 on line 29.

30. Enter the minimum expected transit speed, VMIN, from line 8 on line 30.

31. Enter the ship's beam, B, from line 11 on line 31.

32. Calculate the adjusted beam, B', using the formula indicated from lines 28 through 31. Enter the result on line 32.

33A and 33B. Enter the channel width, W, from line 4 on lines 33A and 33B.

34A and 34B. Enter the adjusted mean, MN', from line 26 on lines 34A and 34B.

35A and 35B. Enter the adjusted beam, B', from line 32 on lines 35A and 35B.

36A and 36B. Enter the adjusted standard deviation, SD', from line 27 on lines 36A and 36B.

37. Calculate the standard deviation multiples to starboard, NS, according to the formula indicated on lines 33A, 34A, 35A, and 36A. Enter the result on line 37.

38. Calculate the standard deviation multiples to port, NP, according to the formula indicated on lines 33B, 34B, 35B, and 36B. Enter the result on line 38.

39. Determine the probability of crossing the starboard channel edge, PS, using Table C-1 and the value of NS from line 37. Enter the result on line 39.

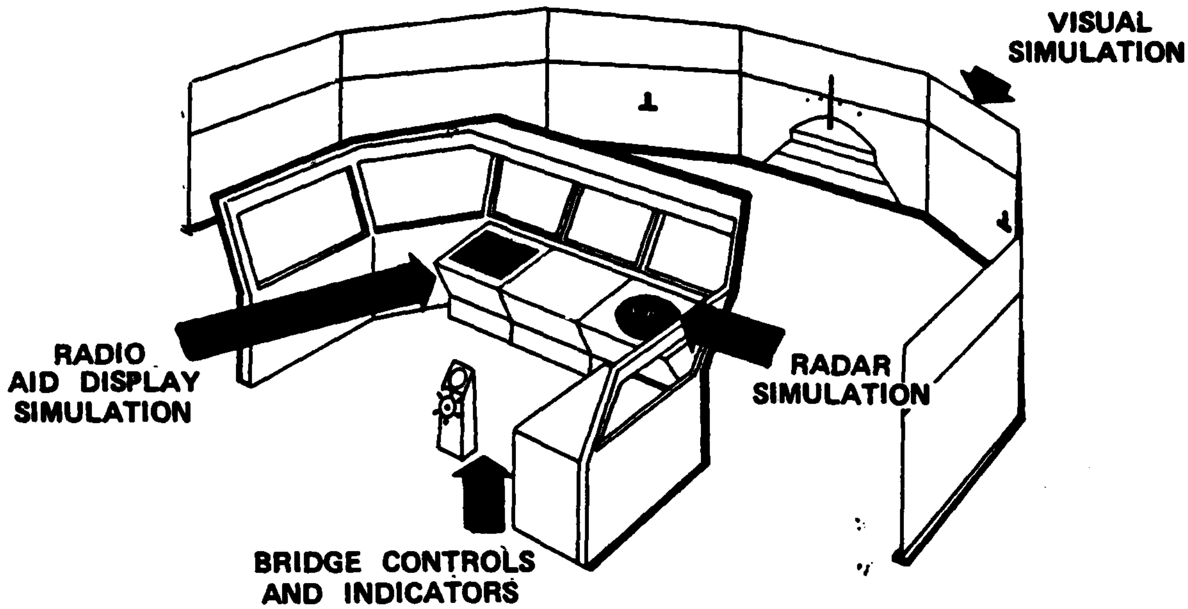
40. Determine the probability of crossing the port channel edge, PP, using Table C-1 and the value of NP from line 37. Enter the result on line 40.

41. Calculate the relative risk factor RRF as the sum of lines 39 and 40. Enter the sum on line 41.

C.5 DETERMINATION OF MN' AND SD' ON A SHIP HANDLING SIMULATOR

Unique and demanding AN placement problems may require the experimental determination of values for the adjusted means (MN') and standard deviations (SD'). This may be accomplished on a shiphandling simulator similar to that utilized to assemble the data in Sections C.2, C.3, and C.4. Figure C-4 shows a diagrammatic picture of the shiphandling simulator assembled by the Coast Guard for this work. The operational features include the simulation of visual aids to navigation (buoys, range lights, fixed aids), radio aids to navigation (graphic, perspective and digital displays) and radar aids to navigation. The effects of limited visibility, daylight conditions, radio signal noise and radio receiver tracker response are simulated. SRA characteristics such as color, shape, and flash periods are simulated. The simulation is controlled from a realistic ship's wheelhouse using typical merchant marine controls and indicators.

A realtime model of ownship's hydrodynamic response controls the simulation. This model accounts for the influences of wind, current, bottom, bank, passing ship and ownship control forces (rudder and RPM).



OPERATIONAL FEATURES

VISUAL SIMULATION: 3RD GENERATION COMPUTER IMAGERY

- 182° HORIZONTAL FIELD OF VIEW
- DAY AND NIGHT CAPABILITY
- BUOYS, RANGE LIGHTS, FIXED LIGHTS, TRAFFIC SHIPS
- OWN SHIP HYDRODYNAMICS

RADIO AIDS SIMULATION

- GENERAL PURPOSE GRAPHIC, PERSPECTIVE AND DIGITAL DISPLAYS
  HEADING AND COURSE VECTORS
  PREDICTION VECTORS
- RADIO AID SIGNAL NOISE AND TRACKER MODELS

WHEELHOUSE SIMULATION

- BRIDGE CONTROLS AND INDICATORS

RADAR SIMULATION

- BUOYS, SHIPS, LAND EDGE DELINIATION
- RACONS

Figure C-4. Shiphandling Simulator Assembled for the United States Coast Guard

Piloting performance on this simulation facility has been experimentally shown to be functional equivalent to that measured on the shiphandling simulator at CAORF (Computer Aided Operations Research Facility) operated by the Maritime Administration.[1] Piloting performance data collected on this simulator will be validated against selected at sea piloting data in the near future.

C.5.1 Application of the Shiphandling Simulator

The determination of the baseline means and standard deviations is accomplished by simulating the AN design alternatives for the channel and operating conditions in question then experimentally determining mean ship's tracks and the standard deviation about the mean track. Typically the experiment consists of requiring 8 pilots to maneuver ownship along the channel in as safe a manner as possible. Ideally, pilots licensed for the channel in question are utilized for the runs. Ship positional data from these runs are statistically analyzed and compared. Plots are made of MN' and SD' as a function of alongtrack position. The relative risk factors may be calculated based on the peak values for SD' in each defined region. Forms XXX, YYY and ZZZ are suitable for calculating RRF commencing at lines 27 and 28 respectively (having completed lines 1-10). The sample application which follows shows typical data available from a simulator analysis. Such presentations are particularly helpful if safety along a particularly difficult section of a channel is in question (e.g., adjacent to a shoal, exiting a turn, entering jetties, etc.).

C.5.2 Sample Simulator Evaluation of Alternate AN Configurations

It is desired to evaluate the exact differences between marking a 500-foot wide channel with gates spaced 5/8 nm versus 1-1/4 nm. The currents in the channel cause a unique piloting problem following a 35-degree turn. Figure C-5 illustrates the channel to be marked with the worst case current condition. Figure C-6 shows the two alternative AN marking schemes. They are denoted as Scenario 2 and Scenario 4. It is decided that the largest vessel to use the channel will be a 30,000 dwt tanker and since only a single berth is accessible, one-way traffic can be assumed. Figure C-7 shows the particulars for ownship.

The shiphandling simulator is programmed with these AN alternatives, the specified environmental conditions and the hydrodynamic model representative of a 30,000 dwt tanker. The data collection program of the simulator is additionally programmed to collect ship data every 475 feet along the channel. Figure C-8 shows the location of these data lines. Experimental runs are now made with qualified shiphandlers, preferably from the port in question. Sufficient experimental control is maintained such that performance effects are not influenced by learning, order of runs, subject differences and the like.

MN' and SD' data are now calculated for each data line and presented in plots similar to those shown in Figures C-9 and C-10, Scenarios 2 and 4 respectively. The numbered data lines are shown as a compressed scale since each data line represents 475 feet. A combined plot of the MN'

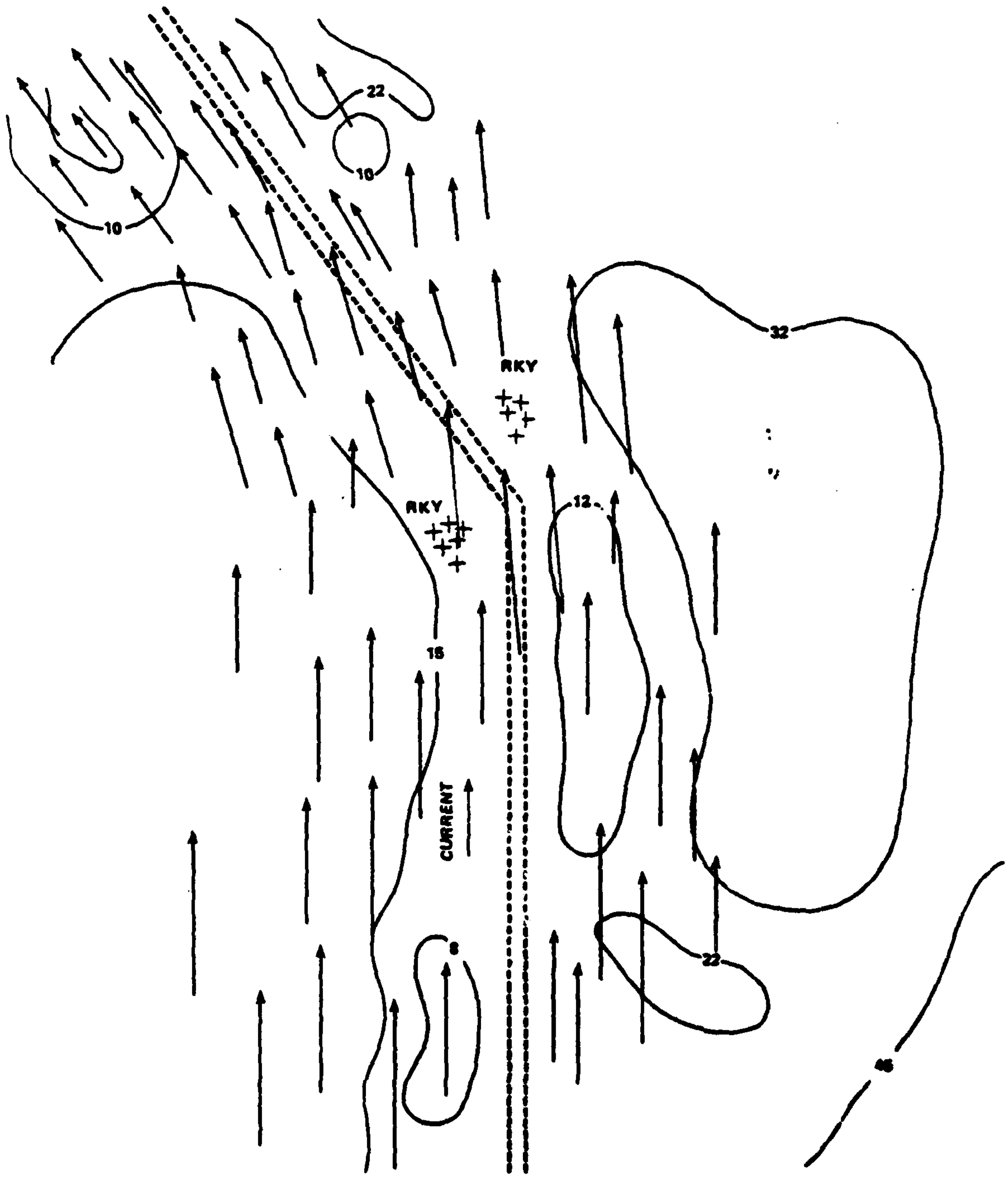


Figure C-5. Worst Case Current Conditions for Channel

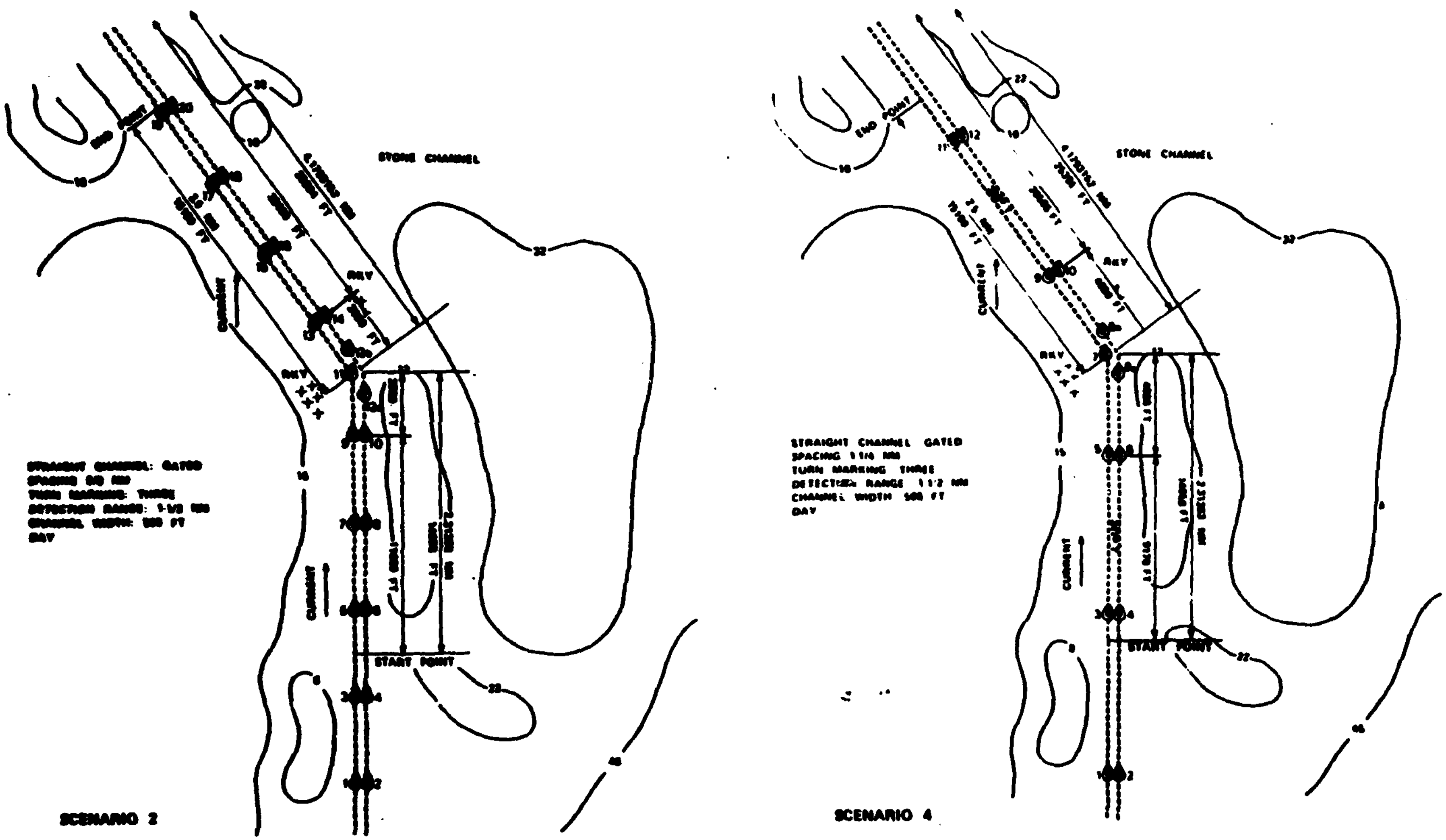


Figure C-6. Alternate AN Configurations to be Evaluated on the Simulator

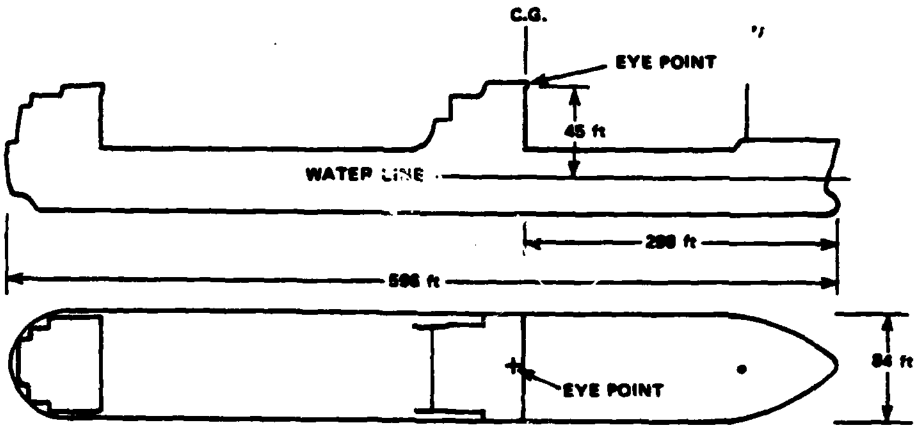


Figure C-7. Plan and Elevation of a 30,000 DWT Tanker

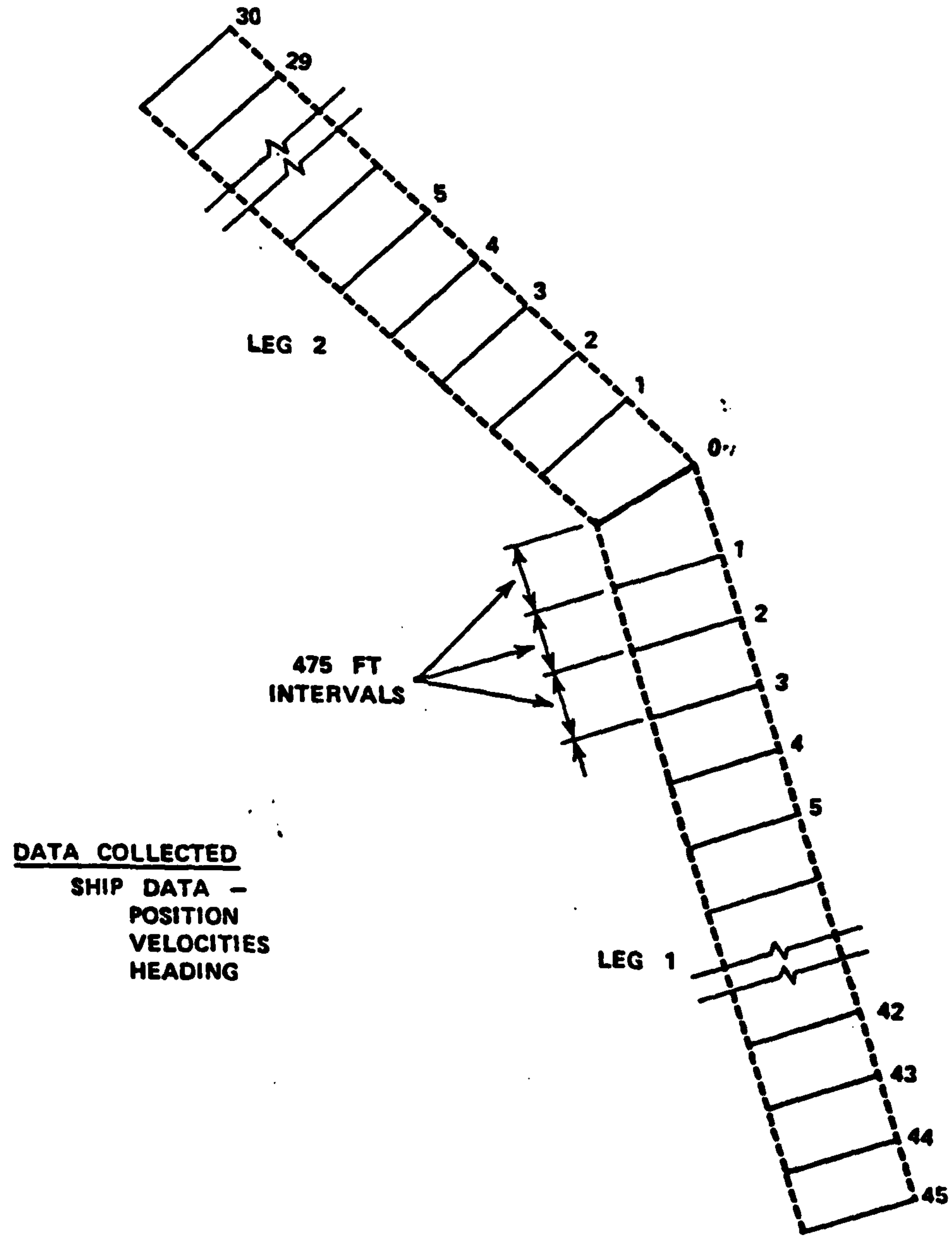


Figure C-8. Location of Data Collection Lines in Channel

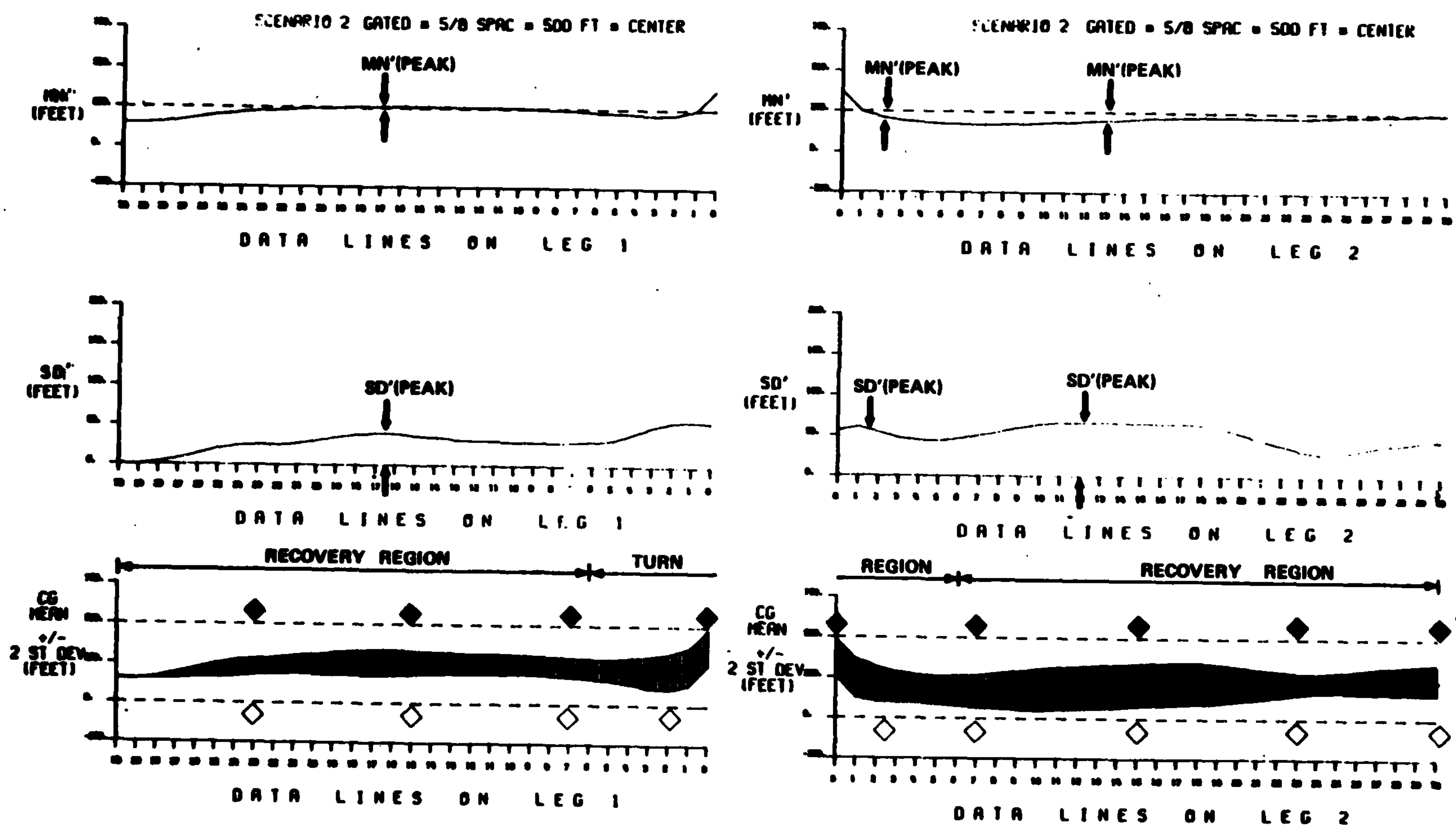


Figure C-9. Plots of Baseline Mean and Standard Deviations for Gated Buoys 5/8 NM Spacing, Scenario 2

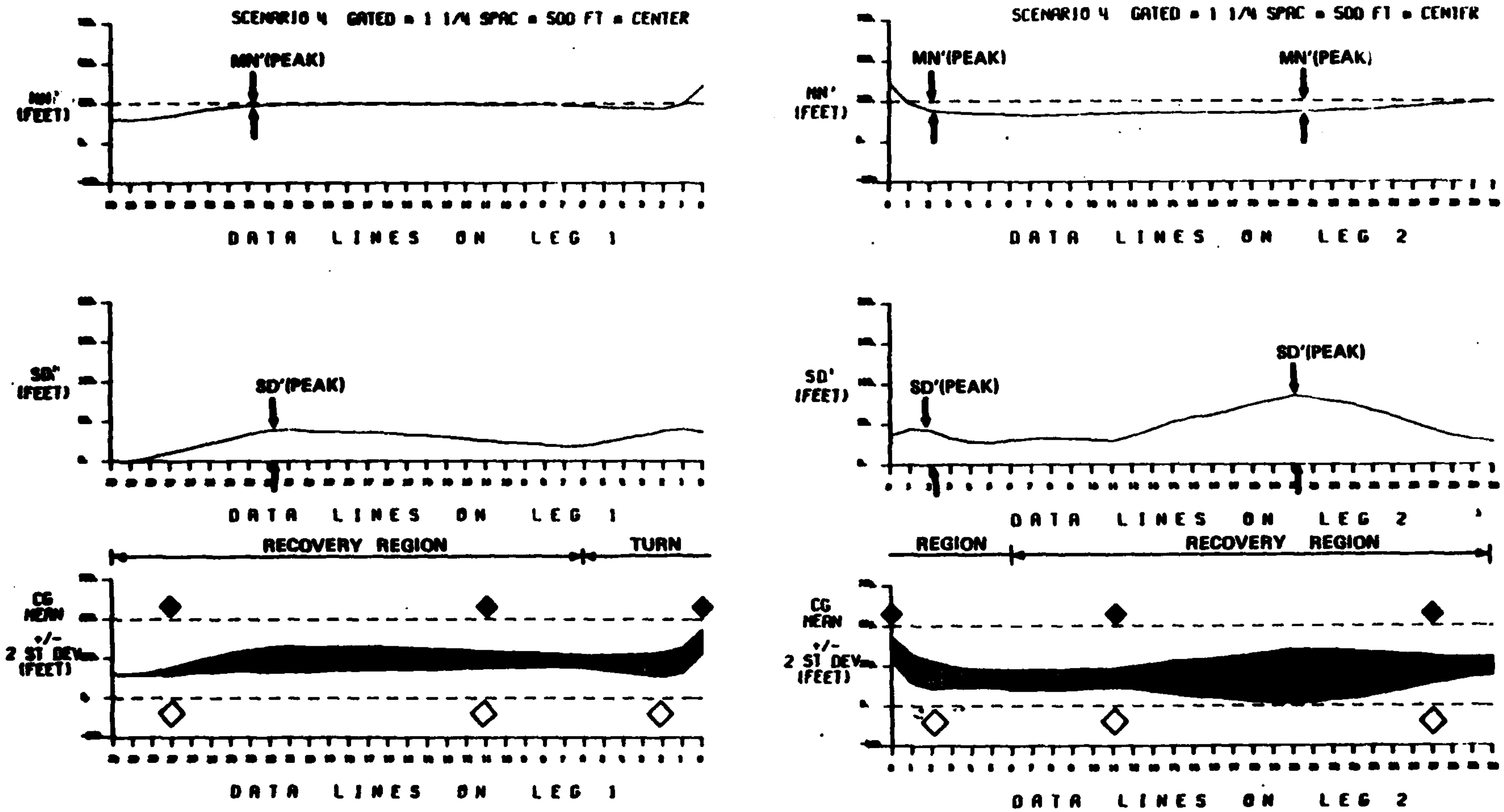


Figure C-10. Plots of Baseline Mean and Standard Deviations for Gated Buoys, 1-1/4 NM Spacing, Scenario 4

track + and - twice SD' is provided on a diagram of the channel edges with buoy locations. Peak values for SD' and the associated MN' are indicated for each region (i.e., recovery (leg 1), turn and recovery (leg 2). Table C-20 provides a summary of these values for the two scenarios. A more graphic comparison of performance in the turns can be made by providing a combined plot (MN' + and - 2 SD') on a scaled plan of the turn. Figure C-11 compares the two scenarios. Buoy locations are indicated.

Given particulars about the current velocities the minimum transit speed and the ship and channel dimensions the relative risk factors can be calculated for each region. Table C-21 lists the RRFs for the following particulars:

W	=	500 feet
VX	=	0.25 knots
VMIN	=	6 knots
L	=	596 feet
B	=	84 feet

It is valuable to note the dependence of SD' and MN' on the alongtrack position. For the 1-1/4 nm gates the region with the highest SD' is between lines 18 and 22 to the starboard side of leg 2. This behavior, however, might not represent a real risk if there is sufficient navigable water beyond the channel edge. Thus, the simulator is seen to provide a great deal more information for comparing alternative AN designs versus the data in Sections C.2, C.3 and C.4 which provide only peak SD' and MN' values.

TABLE C-20. PEAK MN' AND SD' FOR THE CHANNEL REGIONS

	Scenario 2 5/8 nm Spaced Gates	Scenario 4 1-1/4 nm spaced gates
	MN':SD'	MN':SD'
Recovery Region Leg 1	4 : 40 feet	5 : 42 feet
Turn Region	15 : 55 feet	18 : 45 feet
Recovery Region Leg 2	43 : 65 feet	38 : 85 feet

TABLE C-21. RRF FOR THE CHANNEL REGIONS

	Scenario 2 5/8 nm Spaced Gates	Scenario 4 1-1/4 nm Spaced Gates
	RRF	RRF
Recovery Region Leg 1	0.0000	0.0000
Turn	0.0006	0.0000
Recovery Region Leg 2	0.0095	0.0344

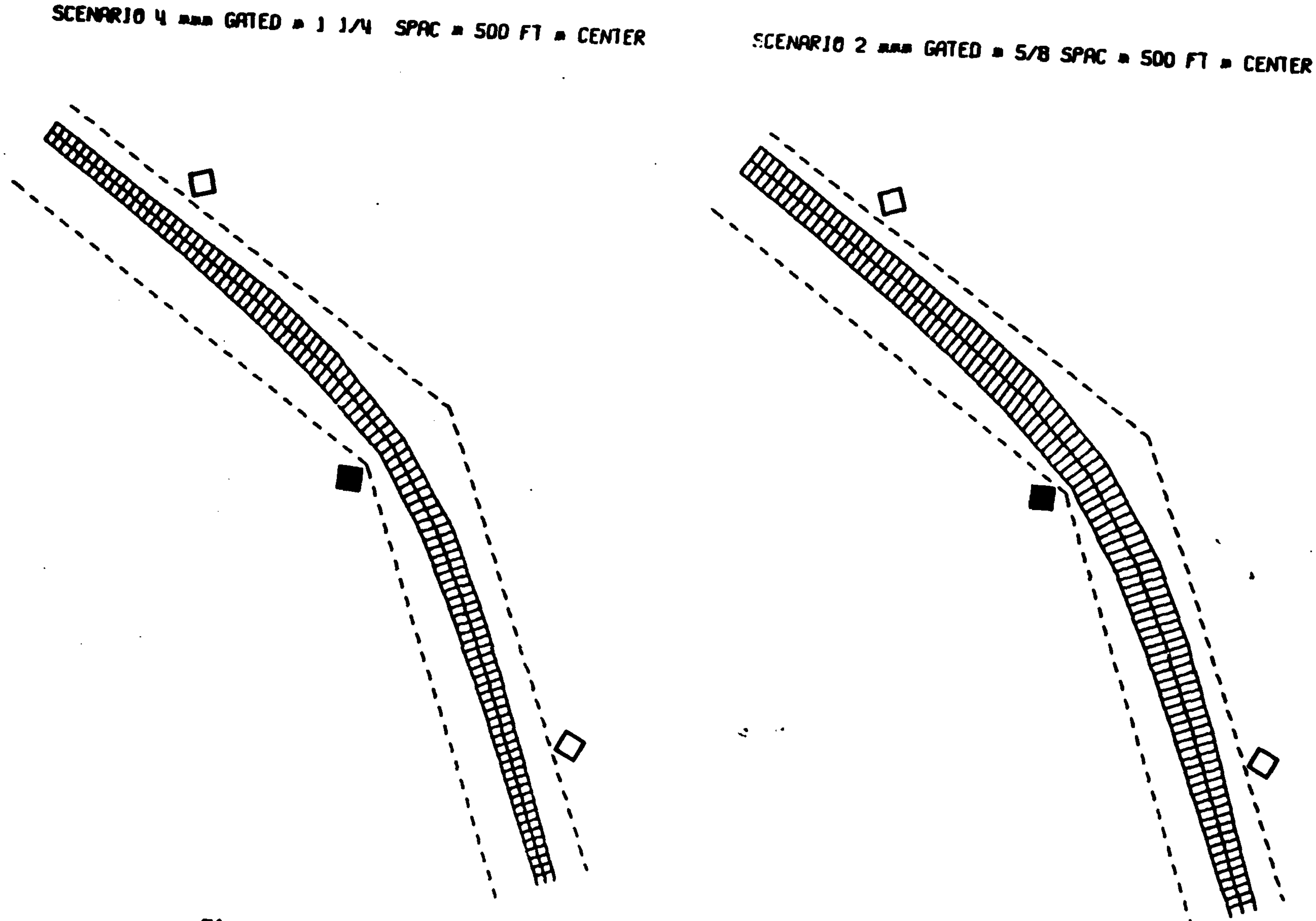


Figure C-11. Mean Track +/- Two Standard Deviations for Turns in Scenarios 2 and 4

EXPLANATORY NOTES FOR APPENDIX C

Note	Data Line	Leg	Description of Condition	Figure	Page	Report
D1	4	2	15 degree 3 buoy day noncutoff turn		5-13	CAORF Prel Perf Data Volume 5
D2			These data are interpolated in a linear fashion between data for the 15 degree and 35 degree turns evaluated experimentally.			
D3	3	2	Scenario 1, 3 buoy turn	28	52	One Side Markings
D4			Not used.			
D5	3	2	Scenario 6, 2 buoy turn	28	52	One Side markings
D6	6	2	15 degree 1 buoy day noncutoff		5-11	CAORF Prel Perf Data Volume 5
D7	2	2	35 degree 1 buoy day noncutoff		5-19	CAORF Prel Perf Data Volume 5
D8	2	2	15 degree turn with high sensitivity ranges	23	47	Range Lights
D9	3	2	35 degree turn high sensitivity ranges	7	19	Range Lights
D10			Data interpolated from high sensitivity range data from 15 degree turn in same proportion that data increased from high to low sensitivity ranges for 35 degree turn.			
D11	1	2	35 degree turn with low sensitivity ranges	10	24	Range Lights
D12	1	2	15 degree 33 buoy day cutoff		5-17	CAORF Prel Perf Data Volume 5

Note	Data Line	Leg	Description of Condition	Figure	Page	Report
D13	1	2	35 degree 3 buoy day cutoff		5-25	CAORF Prel Perf Data Volume 5
D14			Data are assumed to be equivalent to that for noncutoff turns. See footnote D8.			
D15			Data are assumed to be equivalent for noncutoff turn. See footnote D9.			
D16			Data are assumed to be equivalent to noncutoff turns. See footnote D10.			
D17			Data are assumed to be equivalent to noncutoff turns. See footnote D11.			
D18	2	2	15 degree 3 bouy night noncutoff		5-14	CAORF Prel Perf Data Volume 5
D19	2	2	35 degree 3 buoy night noncutoff		5-22	CAORF Prel Perf Data Volume 5
D20			Not used			
D21			Not used			
D22	1	2	15 degree 1 buoy night noncutoff		5-12	CAORF Prel Perf Data Volume 5
D23	4	2	33 degree 1 buoy night noncutoff		5-20	CAORF Prel Perf Data Volume 5
D24			Night performance equivalent to day performance. See footnote D8.			
D25			Night performance assumed equivalent to day performance. See footnote D9.			
D26			Night performance assumed equivalent to day performance. See footnote D10.			

Note	Data Line	Leg	Description of Condition	Figure	Page	Report
D27			Night performance assumed equivalent to day performance. See footnote D11.			
D28	1	2	15 degree 3 buoy night cutoff		5-18	CAORF Prel Perf Data Volume 5
D29	4	2	35 degree 3 buoy night cutoff		5-26	CAORF Prel Perf Data Volume 5
D30			Performance assumed to be equivalent to that for noncutoff. See footnote D8.			
D31			Performance assumed to be equivalent to that for noncutoff. See footnote D9.			
D32			Performance assumed to be equivalent to that for noncutoff. See footnote D10.			
D33			Performance assume to be equivalent to that for noncutoff. See footnote D11.			
D34	2	2	Graphic displays	5	27	RA-1
D35	2	2	Predictor steering display	20	50	RA-1
D36	3	2	Perspective displays	6	28	RA-1
D37	4	2	Simplified digital display	11	41	RA-1
D38	6	2	Digital display with turn recommendations	11	41	RA-1
D39	2	2	Graphic display with heading vector. Performance with perfect position and velocity data assumed to be equivalent to low noise conditions.	16	50	RA-1
D40	1	2	16-meter rms noise with 3-second rise time	24	57	RA2

Note	Data Line	Leg	Description of Condition	Figure	Page	Report
D41	1	2	16-meter rms noise with 12-second rise time	27	62	RA2
D42	1	2	16-meter rms noise with 24-second rise time	30	66	RA2
D43	1	2	32-meter rms noise with 3-second rise time	25	57	RA2
D44	1	2	32-meter rms noise with 12-second rise time	28	63	RA2
D45	3	2	32-meter rms noise with 24-second rise time	31	67	RA2
D46	2	2	16-meter rms noise with 24 second rise time, gryo aiding	33	70	RA2
D47	1	2	32-meter rms noise with 24 second rise time, gyro aiding	34	71	RA2
D48	17	1	Scenario 2 gated 5/8 spacing		1.1-12	Channel Width Prel Perf Data
D49	6	2	Scenario 2 gated 5/8 spacing		2.1-12	Channel Width Prel Perf Data
D50			Data represent a linear interpolation between 5/8 and 1 1/4 nm spacing for the given maximum drift angle condition and configuration.			
D51	21	1	Scenario 4 gated 1 1/4 nm spacing		1.1-14	Channel Width Prel Perf Data
D52	20	2	Scenario 1 gated 1 1/4 nm spacing. Data selected beyond region of incorrect wind effect.	7	19	One Side Markings

Note	Data Line	Leg	Description of Condition	Figure	Page	Report
D53	20	1	Scenario 1 staggered 5/8 nm spacing		1.1-11	Channel Width Prel Perf Data
D54	14	2	Scenario 1 staggered 5/8 nm spacing		2.1-11	Channel Width Prel Perf Data
D55	23	1	Scenario 3 staggered 1 1/4 nm spacing. The mean selected from data line 17 to account for zigzag piloting strategy.		1.1-13	Channel Width Prel Perf Data
D56	9	2	Scenario 1 staggered 1 1/4 nm spacing		E-3	Ship Variables
D57	6	1	Scenario 4 inside marking 5/8 nm spacing	12	27	One side marking
D58	12	2	Scenario 4 one side marking 5/8 nm spacing	12	27	One side marking
D59	5	1	Scenario 2 one side marking 1 1/4 nm spacing	12	27	One side marking
D60	13	2	Scenario 2 inside marking 1 1/4 nm spacing	12	27	One side marking
D61	11	1	Scenario 1 high sensitivity range lights	8	21	Range Lights
D62	6	2	Scenario 1 high sensitivity range lights	8	21	Range Lights
D63	5	1	Scenario 2 low sensitivity range lights	10	24	Range Lights
D64	6	2	Scenario 2 low sensitivity range lights	10	24	Range Lights

Note	Data Line	Leg	Description of Condition	Figure	Page	Report
D65			Analysis of pilot performance during passing maneuvers conducted in the CAORF experiment indicate that (1) the average distance between ships when the passing maneuver was initiated is approximately 3/4 nm and (2) that the pilots concentrate on successfully maneuvering to a comfortable distance abeam the traffic ship rather than concentrating on maneuvering to a particular position in the channel. This behavior resulted in a mean crosstrack position of ownship during the passing maneuver to be approximately 1/6 of the channel width to the right of the centerline. During the channel width experiment when the pilot was requested to maneuver to the position 1/4 of the channel width to the right of the centerline, the resultant tracks indicated that the approximate mean track was actually 1/6 of the channel width to the right of the channel centerline. It is assumed therefore, that the approximate mean position of ships during a port-to-port passing is approximately 1/6 of the channel width to the right of the centerline. Since both ships approach the passing point with equal crosstrack variability as a function of the aids to navigation, it is further assumed that the crosstrack variability (standard deviation) will not be decreased during the passing maneuver. It is assumed, therefore, that the baseline standard			

Note	Data Line	Leg	Description of Condition	Figure	Page	Report
			deviation values as a function of maximum drift angle, AN spacing, and AN configuration will not change as a function of two-way traffic.			
D66	22	1	Graphic vectors	5	27	RA1
D67	9	2	Graphic vectors	6	28	RA1
D68	24	1	Predictor steering display	20	56	RA1
D69	5	2	Predictor steering display	21	57	RA1
D70	19	1	Perspective display	5	27	RA1
D71	14	2	Perspective display	6	28	RA1
D72	25	1	Simplified digital display	10	40	RA1
D73	11	2	Simplified digital display	11	41	RA1
D74	25	1	Digital display with turn recommendations	10	40	RA1
D75	15	2	Digital display with turn recommendations	11	41	RA1
D76	22	1	Graphic display with heading vector: Performance with low noise assumed to be equivalent to perfect position and velocity data.	15	49	RA1
D77	9	2	Graphic display with heading vector: Performance with low noise assumed to be equivalent to that with perfect position and velocity data.	16	50	RA1

Note	Data Line	Leg	Description of Condition	Figure	Page	Report
D78	10	1	16-meter rms, 3-second rise time	24	56	RA2
D79	9	2	16-meter rms, 3-second rise time	24	56	RA2
D80	9	1	16-meter rms, 12-second rise time	27	62	RA2
D81	6	2	16-meter rms, 12-second rise time	27	62	RA2
D82	11	1	16-meter rms, 24-second rise time	30	66	RA2
D83	6	2	16-meter rms, 24-second rise time	30	66	RA2
D84	10	1	32-meter rms, 3-second rise time	25	57	RA2
D85	12	2	32-meter rms, 3-second rise time	25	57	RA2
D86	11	1	32-meter rms, 12-second rise time	28	63	RA2
D87	8	2	32-meter rms, 12-second rise time	28	63	RA2
D88	11	1	32-meter rms, 24-second rise time	31	67	RA2
D89	6	2	32-meter rms, 24-second rise time	31	67	RA2
D90			Data represent performance with perfect position and velocity data. See note D76.			
D91			Data represent performance with perfect position and velocity data. See note D77.			
D92	11	1	16-meter rms, 24-second rise time, gyro aided	33	70	RA2

Note	Data Line	Leg	Description of Condition	Figure	Page	Report
D93	6	2	16-meter rms, 24-second rise time, gyro aided	33	70	RA2
D94	9	1	32-meter rms, 24-second rise time, gyro aided	34	71	RA2
D95	9	2	32-meter rms, 24-second rise time, gyro aided	34	71	RA2
D96	15	1	Scenario 2 gated 5/8 nm spacing		1.1-12	Channel Width Prel Perf Data
D97	20	2	Scenario 2 gated 5/8 nm spacing. Data line 20 selected beyond incorrect wind region.		2.1-12	Channel Width Prel Perf Data
D98			Data are a linear interpolation between 5/8 nm and 1 1/4 nm spacing for equivalent maximum drift angles and AN configurations.			
D99	15	1	Scenario 4 gated 1 1/4 nm		1.1-14	Channel Width Prel Perf Data
D100	22	2	Scenario 1 gated 1 1/4 nm spacing	7	19	One Side Markings
D101	12	1	Scenario 1 staggered 5/8 nm spacing		1.1-11	Channel Width Prel Perf Data
D102	19	2	Scenario 1 staggered 5/8 nm spacing		2.1-11	Channel Width Prel Perf Data
D103	15	1	Scenario 3 staggered 1 1/4 nm spacing		1.1-13	Channel Width Prel Perf Data
D104	19	2	Scenario 1 staggered 1 1/4 nm spacing		E-3	Ship Variables
D105	6	1	Scenario 4 inside markings 5/8 nm spacing	12	27	One Side Marking

Note	Data Line	Leg	Description of Condition	Figure	Page	Report
D106	15	2	Scenario 4 inside markings 5/8 nm spacing	12	27	One Side Marking
D107	5	1	Scenario 2 inside marking 1 1/4 nm spacing	12	27	One Side marking
D108	15	2	Scenario 2 inside marking 1 1/4 nm spacing	12	27	One Side marking
D109	4	1	Scenario 1 high sensitivity range lights	8	21	Range Lights
D110	15	2	Scenario 1 high sensitivity range lights	8	21	Range Lights
D111	5	1	Scenario 2 low sensitivity range lights	10	24	Range Lights
D112	15	2	Scenario 2 low sensitivity range lights	10	24	Range Lights
D113			Data for two-way traffic assumed to be equivalent to that for one-way traffic with 1/6 of the channel width added to the mean values. See footnote D65 for explanation of the use of the value 1/6 of the channel width.			
D114	6	1	Graphic vectors	5	27	RA1
D115	16	2	Graphic displays	6	28	RA1
D116	11	1	Predictor steering display	20	56	RA1
D117	28	2	Predictor steering display	21	57	RA1

Note	Data Line	Leg	Description of Condition	Figure	Page	Report
D118	12	1	Perspective displays	5	27	RA1
D119	15	2	Perspective displays	6	28	RA1
D120	19	1	Simplified digital display	10	40	RA1
D121	26	2	Simplified digital display	11	41	RA1
D121	19	1	Digital display with turn recommendations	10	40	RA1
D123	16	2	Digital display with turn recommendations	11	41	RA1
D124	6	1	Graphic display with heading vector: Performance with low noise assumed to be equivalent to that with perfect position and velocity data.	15	49	RA1
D125	15	2	Graphic display with heading vector: Performance with low noise assumed to be equivalent for perfect position and velocity data.	16	50	RA1
D126	7	1	16-meter rms, 3-second rise time	24	56	RA2
D127	30	2	16-meter rms, 3-second rise time	24	56	RA2
D128	9	11	16-meter rms, 12-second rise time	27	62	RA2
D129	15	2	16-meter rms, 12-second rise time	27	62	RA2
D130	5	1	16-meter rms, 24-second rise time	30	66	RA2
D131	17	2	16-meter rms, 24-second rise time	30	66	RA2
D132	6	1	32-meter rms, 3-second rise time	25	57	RA2

Note	Data Line	Leg	Description of Condition	Figure	Page	Report
D133	30	2	32-meter rms, 3-second rise time	25	57	RA2
D134	6	1	32-meter rms, 12-second rise time	28	63	RA2
D135	17	2	32-meter rms, 12-second rise time	28	63	RA2
D136	6	1	32-meter rms, 24-second rise time	31	67	RA2
D137	15	2	32-meter rms, 24-second rise time	31	67	RA2
D138			Data assumed to be equivalent for perfect position and velocity data. See note D124.			
D139			Data assumed to be equivalent for perfect position and velocity data. See note D125.			
D140	6	1	16-meter rms, 24-second rise time, gyro aided	33	70	RA2
D141	15	2	16-meter rms, 24-second rise time, gyro aided	33	70	RA2
D142	6	1	32-meter rms, 24-second rise time, gyro aided	34	71	RA2
D143	9	2	32-meter rms, 24-second rise time, gyro aided	34	71	RA2

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